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Tillage system regulates the soil moisture tension, penetration resistance and temperature responses to the temporal variability of precipitation during the growing season**

Edward Wilczewski[1]*, *Irena Jug*[2], *Jerzy Lipiec*[3], *Lech Gałęzewski*[1], *Boris Đurđević*[2], *Anna Kocira*[4], *Bojana Brozović*[2], *Monika Marković*[2], *and Danijel Jug*[2]

[1]Faculty of Agriculture and Biotechnology, Bydgoszcz University of Science and Technology, Prof. S. Kaliskiego 7, 85-796 Bydgoszcz, Poland
[2]Faculty of Agrobiotechnical Sciences Osijek, Josip Juraj Strossmayer University of Osijek, Vladimira Preloga 1, HR-31000 Osijek, Croatia
[3]Institute of Agrophysics, Polish Academy of Sciences, Doświadczalna 4, 20-290 Lublin, Poland
[4]Institute of Human Nutrition and Agriculture, The University College of Applied Sciences in Chełm, Wojsławicka 8B, 22-100 Chełm, Poland

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A b s t r a c t. At present there is little information available concerning the relationship between the tillage system applied and the soil moisture tension, penetration resistance, soil moisture content, and temperature responses to the temporal variability of precipitation under the semi-arid Mediterranean environment. The aim of this study was to determine the effects of standard tillage (ploughing to 25-35 cm) and conservation tillage shallow (loosening to 10 cm) on temporal changes in the three properties in response to the precipitation pattern in Croatia. The temporal changes in soil moisture tension were determined using Watermark sensors (at 15 and 30 cm), and penetration resistance (at 0-30 cm) was determined with an Eijkelkamp penetrometer in spring under winter wheat. After heavy precipitation, the soil moisture tensions were similar irrespective of the tillage system used and the measurement depth, while with the increasing length of the period without precipitation (using the last precipitation incident as the starting timepoint), the soil moisture tensions increased to a greater extent under conservation tillage shallow as compared to standard tillage. The temporal changes in soil moisture tension in response to precipitation were less sensitive at the 30 than at the 15 cm depth. The adoption of conservation tillage shallow increased the amount of topsoil organic matter as compared to standard tillage. This study indicates that conservation tillage shallow is a promising practice in terms of soil quality improvement and crop productivity under highly variable Mediterranean climate conditions.

K e y w o r d s: conservation tillage, soil physical properties, Stagnosol soil, winter wheat

*Corresponding author e-mail: edward@pbs.edu.pl
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1. INTRODUCTION

The applied tillage system is one of the most important factors influencing the physical properties of the soil (Martins *et al.*, 2021; Wang *et al.*, 2023). It has a significant impact on biological activity of the soil and on the possibility of ensuring conditions for the proper growth and development of crops (Piotrowska and Wilczewski, 2020; Souza *et al.*, 2021). Penetration resistance (PR) is especially important as it is a result of soil water content and bulk density (Lardy *et al.*, 2022) which are largely influenced by both tillage systems and field traffic (Jug *et al.*, 2021; Wang *et al.*, 2022). Since measurements of PR are relatively rapid, they are suitable for the evaluation of the mechanical impedance to root elongation (Colombi *et al.*, 2018; Gliński and Lipiec, 2018) and the effects of tillage on pore and aggregate structure (Dexter *et al.*, 2007, Alaoui *et al.*, 2011), the size of the structural units and also the structural discontinuities in the soil profile (Whalley *et al.*, 2000; Lowery and Morrison, 2002).

The soil moisture tension (SMT) or the soil matric potential constitutes the force with which water is held in the soil and thereby provides essential information concerning soil water availability to plants (Whalley *et al.*, 2000) and is an early warning drought signal at the field scale (Lorite *et al.*, 2018; Asmamaw, 2017). Furthermore, it indirectly affects other significant plant growth factors such as the soil temperature (T), PR and aeration and therefore is a significant link between the soil properties and plant health (Dai *et al*., 2022). Soil T is essential for many soil processes including organic matter decomposition (Bradford *et al*., 2016), and root and shoot growth (Gliński and Lipiec, 2018; Al-Kaisi and Lowery, 2017). Data concerning soil T are useful for the estimation of soil thermal conductivity (Wang *et al*., 2007), soil thermal diffusivity (Zhou *et al*. 2018), surface-sensible and latent heat fluxes, and for the recognition of the physical process of soil water-heat migration (Heitman *et al*., 2008; Wang and Yang, 2018).

These physical properties of soil are substantially influenced by shifting from conventional (intensive) tillage coupled with monocropping and the partial recycling of crop residues to conservation tillage systems including practices involving minimized soil disturbance, permanent soil cover with crop residues and diversified crop rotation (Powlson *et al*., 2016; Gonzalez-Sanchez *et al*., 2019; Devkota *et al.*, 2022; Du *et al*., 2022). These practices are the main components of conservation agriculture (CA) (Ranaivoson, 2017; Xiao, 2021; Francaviglia *et al*., 2023) which has been shown to be suitable for improving soil structure and organic carbon sequestration (Kocira *et al*., 2020; Hussain, 2021; Mia *et al*., 2023), soil moisture conservation and in the reduction of erosion (Kocira *et al*., 2020; Mia *et al*., 2023), thereby sustaining soil health and reducing soil degradation (Kocira *et al*., 2020; Jug *et al*., 2021; Jayaraman and Dalal, 2022) and also lowering the input costs of crop production (Busari *et al*., 2015; Smith *et al*., 2021; Musto *et al*., 2023). Therefore, in recent years, CA has been promoted as an alternative to conventional agriculture in many parts of the world (Jug *et al*., 2019; Hussain *et al*., 2021; Hessel *et al*., 2022). In global terms, conservation agriculture practices are now being implemented on ~ 180 million ha which corresponds to approximately ~14% of all arable land (Jayaraman and Dalal, 2022).

The effect of CA practices on the physical properties of the soil and its organic matter content depends on the prevailing climatic conditions. Recent global literature reviews (Du *et al*., 2022; Francaviglia *et al*., 2023) indicate that relatively few studies concerning the effects of CA have been performed under semi-arid Mediterranean conditions where the predominantly used conventional tillage leads to the unsustainable depletion of SOM and water resources. Therefore, the research and adoption of conservation tillage practices in order to improve soil quality in the Mediterranean environment remains challenging. This challenge could be supported by the high degree of variability of climatic elements (Ceglar, *et al*., 2018) which are not conducive to the accumulation of SOM and the storage of water (Musto *et al*., 2023). In this study, the aim was to recognize how the soil moisture content (MC), PR, and T respond to temporal precipitation patterns during the growing season, two tillage systems are compared *i.e*., conventional and conservation under the Mediterranean conditions which prevail in Croatia.

2. MATERIAL AND METHODS

2.1. Study site and experimental design

The field experiment was performed in 2021-2023 on the Stagnosol soil type (WRB, 2015), site Čačinci (17.86336' E, 45.61316' N, Alt. 111 m, 0-1% slope). The experimental field is located in the Central Pannonian agricultural subregion in the most productive agricultural area of Croatia (Jug *et al*., 2019). Climatically and geographically, the experimental region belongs to the Pannonian Basin, which is characterized by a high degree of variation of climatic elements (Ceglar *et al*., 2018). The same pattern, especially in terms of variations in precipitation and temperature was noted on the experimental site. The long-term average temperature of Čačinci (1984-2022) is 11.4°C and the average precipitation is 792 mm, with respective variation ranges of 9.4-12.9°C and 320-1240 mm.

Samples for the analysis of basic soil chemical properties, soil texture, and macroaggregate stability were taken from the soil profile, and samples for the determination of soil physical properties (Table 1) were taken from three different soil layers (0-15, 15-30, and 30-45 cm depth).

The particle-size distribution was found to be 10% sand (2-0.05 mm), 61% silt (0.05-0.002 mm) and 29% clay (<0.002 mm) in the soil layer down to 0.32 m depth. A similar texture was found in the 0.32-0.65 m layer (10, 58 and 34% for particle sizes of 2-0.05, 0.05-0.002 and < 0.002 mm, respectively). There is an increase in sand content in the next layer (0.65 to 3.3 m) to 11-31% and a decrease in the clay content (2 to 3.3 m) to 12-15%. In accordance with the analyses conducted in the autumn of 2022 (after soybean harvest), the first layer of soil (down to a 0.3 m depth) contained 2.83% organic matter (SOM) and 4.8 mg 100 g^{-1} soil of Al-P_2O_5 and 11.15 mg 100 g^{-1} soil of Al-K_2O and had a pH (in M KCl) of 3.92 and a hydrolytic acidity (Hy) of 7.48 ($cmol^{(+)}$ kg^{-1}). The SOM and Hy decreased in the lower layers (0.3-3.3 m) respectively to 0.28-0.83% and 1.79-4.07 ($cmol^{(+)}$ kg^{-1}).

Table 1. Soil physical properties on experimental plots

Treatment	Soil depth (cm)	FC (% vol.)	ρ_b (g cm^{-3})	ρ_s
ST	0-15	37.22	1.45	2.60
	15-30	35.59	1.47	2.60
	30-45	33.86	1.59	2.67
CTS	0-15	38.24	1.48	2.57
	15-30	37.30	1.49	2.60
	30-45	37.03	1.53	2.67

ST – standard tillage, CTS – conservation tillage shallow, FC – field capacity, ρ_b – bulk density, ρ_s – particle density.

The experiment was started in October 2020 using a stationary setup, with two different soil tillage treatments: standard tillage (ST) (which includes: ploughing up to 25-30-35 cm and a different secondary tillage treatment – variations depend on the crops grown); conservation soil tillage shallow (CTS) (soil loosening up to 10 cm, with a minimum soil surface coverage of 50% of crop residues. Ploughing was performed with the KUHN Multi-master 121 and soil loosening with the Pegoraro MEGA DRAG 7 adjusted to the expected working depths. The size of the basic plot for each tillage system was 160 m^2. The experimental crops are organized as a three-crop sequence in rotation. Crop rotation basically includes maize (growing season in 2021), soybean (growing season in 2022; fore-crop for winter wheat in the experiment), winter wheat (growing season in 2022/2023), and the cover crop grown each time in sequence after the winter wheat. Winter wheat, cultivar Indira, was sown in autumn 2022 (October 20) in optimal soil conditions. Sowing was performed with a no-till seeder Horsch Express 3 TD, at a sowing rate of 250 kg ha^{-1}, and at a 3-5 cm depth with an interrow space of 15 cm. After all of the soil tillage preparation and sowing was complete, the soil surface was covered from 85 to 90% on average. In the experimental field from which the presented results were obtained, the winter wheat was sown in autumn 2022.

The experiment was set up as a complete randomized block design (RCBD) with four repetitions. The size of the basic experimental plot for each individual tillage treatment was 640 m^2.

2.2. Measurement methods

Soil moisture tensions were measured in plots with standard tillage (ST) and with Conservation tillage shallow (CTS) using Watermark soil moisture sensors 200SS-15. For each soil tillage system, 8 sensors were placed at two different soil depths: 15 and 30 cm. The sensors were connected with data loggers (Watermark Monitor 900M, Irrometer Company Inc.). Measurements of SMT were carried out at the time of spring tillering, shooting and ear formation, which are crucial for the number of shoots and ears per m^2 as well as the number of grains per ear. Readings were taken each hour in the period from 14 March to 16 May 2023. Based on data from 4 sensors for each soil depth, the average data for each day was calculated.

Measurements of soil MC and T were carried out in the upper soil layers (0-10 cm deep). The measurement was carried out 5 times (17 and 31 March, 17 April, 2 and 17 May) in 8 places for each tillage system with a TDR WET-2/d-02 probe, equipped with a HH2 reader.

The measurement of soil PR was carried out 5 times as was the case with MC and T, in 12 places for each tillage system. These measurements were made using an Eijkelkamp manual penetrometer 06.01.SA. Measurements of PR were completed up to a depth of 30 cm, and the values were expressed in terms of the average data for each soil layer as follows: 0-5, 5-10, 10-15, 15-20, 20-25, and 25-30 cm.

The soil organic matter (SOM) content was measured in the upper soil layers (0-15 cm deep) using a modified Walkley-Black method (Bahadori and Tofighi, 2016).

The total dry biomass of the wheat was measured on 26 April 2023, after all of the aboveground parts of the plants were clipped from the sampling area (0.25 m^2 from each plot). The biomass was dried at 60°C for 48 h and weighed on a laboratory balance.

The field-water capacity (FC) was calculated indirectly with soil saturation measurements, filter paper sheets in Kopecky cylinders (volume 100 cm^3) were used for 24 h (2 times), this was followed by weighing, drying and weighing again (Škorić, 1982). The differences between these measured values represent the amount of water at FC. FC was calculated using a method which represents the retention capacity (*RK*), it may be calculated using the following formula and expressed in terms of volume (%):

$$RK = \frac{loss\ upon\ drying}{100\ \mathtt{cm}^3}100,$$

where: loss upon drying – amount of water loss during drying (cm^3).

2.3. Statistical analysis of the results

The results concerning soil MC and T as well as the PR of the soil were subjected to a one-way analysis of variance including the effect of the soil tillage system on these properties. An analysis of PR was performed separately for particular soil layers. When significant treatment effects were found, Tukey's test was used at a significance level of $p \leq 0.05$ in order to compare the treatment means.

3. RESULTS

3.1. Precipitation patterns

From 14 March to 16 May 2023, 65 precipitation events were recorded, this amounted to a cumulative total of 304 mm throughout the research period (Fig. 1). The minimum precipitation for any single event was 0.2 mm and the maximum was 63 mm. The most widespread precipitation events were below 5.0 mm, which accounted for nearly 79% of all precipitation events. Other precipitation events, corresponding to 5.1-20.0, 20-40 mm and precipitation above 40 mm, accounted respectively for 15, 5 and 1% of all precipitation events.

3.2. Soil organic matter, bulk density and field-water capacity

In the third year of the experiment (2022) SOM content in the 0-15 cm layer was greater under CTS (3.14%) as compared to ST (2.88%) (Fig. 2). The soil under both tillage systems had a similar bulk density (ρ_b) and particle density (ρ_s) (Table 1). The values of both densities increased with depth. Irrespective of the tillage system used, the ρ_b value

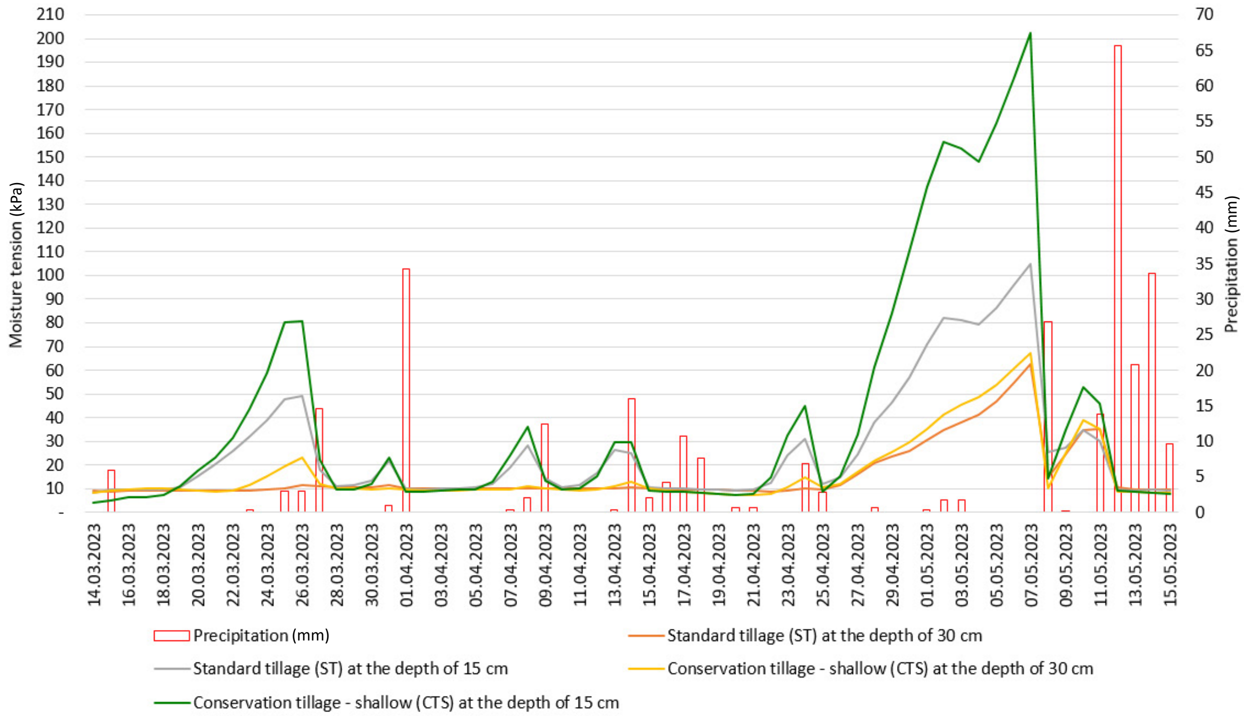

Fig. 1. Precipitation and soil moisture tensions (SMT) under different tillage systems.

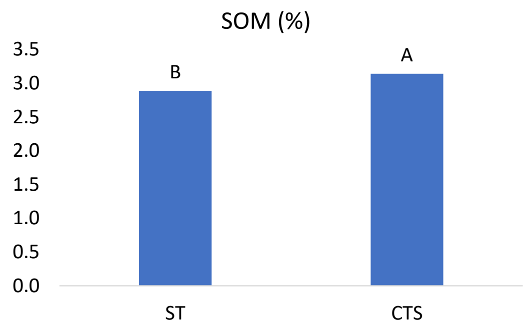

Fig. 2. Soil organic matter (SOM) content at a depth of 0-15 cm under standard tillage (ST) and conservation tillage shallow (CTS). Different letters represent significant differences at the p≤0.05 probability level.

was higher at a depth of 30-45 cm (1.53-1.59 g cm^{-3}) than it was at depths of 0-15 and 15-30 cm (1.45-1.49 g cm^{-3}). The corresponding values for ρ_s were 2.67 g cm^{-3} and 2.57-2.60 g cm^{-3} respectively. The field-water capacity tended to be greater under CTS than ST for all depths. The lowest increase occurred at a depth of 0-15 cm (38.24 *vs* 37.22% vol.) and the highest at a depth of 30-45 cm (37.03 *vs* 33.86% vol.).

3.3. Temporal variations in soil moisture tension (SMT) under the two tillage systems

The daily variations in SMT under the two tillage systems were, in general, consistent with the temporal variations in the amounts of precipitation (Fig. 1). During and for a few days after the heavy precipitation events (on 14-15 March, 27 March, 1 April, 8-9 April, 14-18 April, 24-25 April and 12-15 May) the SMTs under both of the tillage systems and depths varied to a similar extent from approx. 5 to 10 kPa which corresponded to near-saturation conditions and field-water capacity. However, with the increasing length of the period between heavy precipitation events the SMTs increased along with more pronounced differences between the tillage systems. For example, the SMT at a depth of 15 cm on 24 April (after 6 days from the end of the heavy precipitation event on 14-18 April) was greater in CTS than ST by ≈14 kPa (45 *vs* 31), whereas the corresponding difference at the shooting growth stage on 7 May (after 11 days from the end of a considerable precipitation on 24-25 April) a depth of 30 cm were ≈ 5 kPa (67.4 *vs* 62.8 kPa) and at a depth of 15 cm ≈ 97 kPa (202 *vs* 105 kPa). The data above implies that the effect of Stagnosol tillage on temporal changes in SMT in response to precipitation distribution was much more sensitive at the 15 cm than at the 30 cm depth.

3.4. Penetration resistance

As may be observed in Fig. 3, the soil PR for the whole profile for the first three (from 17 March to 17 April) and fifth measurement date (17 May) was low, varying from 0.5 to 1.5 MPa depending on the tillage system. In the top layer (0-10 cm) it was not significantly influenced by the tillage system used. In the deeper soil layers (10-30 cm) it was usually significantly higher in the CTS than in the ST plots with the exception of the 15-20 cm layer on 31 March

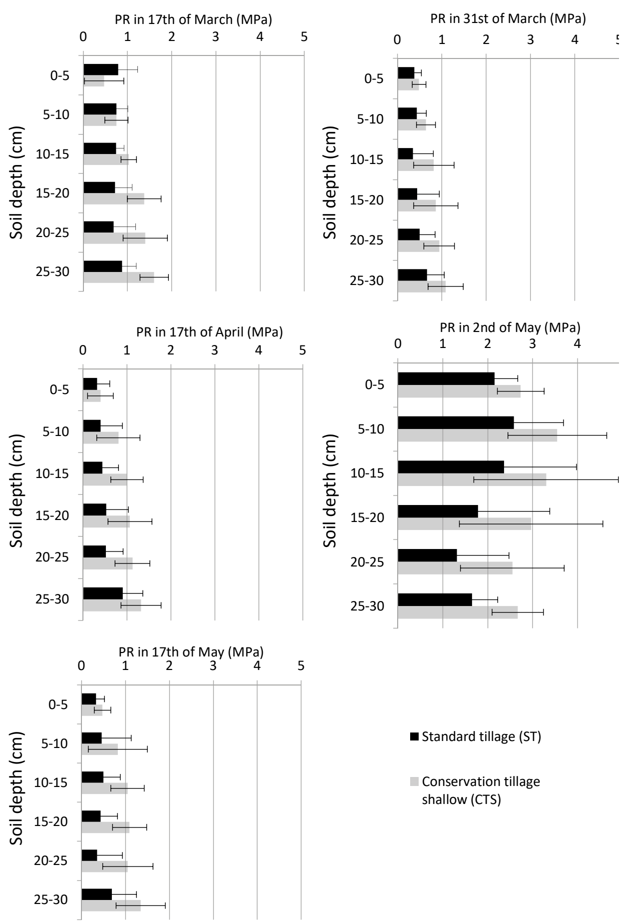

Fig. 3. Penetration resistance (PR) of the soil, in early spring (MPa). Bars represent the means and Tukey's confidence half intervals.

Table 2. Moisture content (MC) and temperature (T) of the upper layer of soil (0-10 cm deep) under different tillage systems

Measurement time	ST	CTS	Mean	LSD 0.05
		Moisture content (%, vol.)		
17th of March	34.34	39.09	36.72	4.22
31st of March	31.05	32.98	32.02	ns
17th of April	36.40	39.31	37.86	ns
2nd of May	23.93	27.55	25.74	ns
17th of May	39.11	38.05	38.58	ns
		Temperature (°C)		
17th of March	9.73	9.88	9.80	ns
31st of March	10.35	10.85	10.60	ns
17th of April	10.69	10.39	10.54	0.22
2nd of May	14.72	14.15	14.44	ns
17th of May	14.25	14.43	14.34	ns

ST – standard tillage, CTS – conservation tillage shallow, LSD 0.05 – lowest significant difference according to Tukey's test, ns – non-significant differences.

and in the 25-30 cm layer on 17 April, when the tillage effect system was not statistically different. On the fourth measurement date (2 May), PR was appreciably higher (1.3-3.5 MPa) as compared to the other measurement dates irrespective of the tillage system used and the depth. Significantly greater PR values occurred under CTS as compared to ST at three depths within 0-5 and 20-30 cm. Regardless of the tillage system used and the measurement time, the highest PR values (with the exception of 2 May) were recorded at a depth of 25-30 cm.

3.5. Moisture content and temperature of the upper layer of the topsoil

Due to the high rainfall totals in the first half of March, very high soil MC in the surface soil layer was found for the first measurement (March 17) (Table 2). It was significantly higher under the conditions of CTS than ST. The very high humidity of this soil layer was also found on 31 March, 17 April, and 17 May. However, no significant influence of the tillage system on the value of this parameter was found on these dates. For the fourth measurement time (2 May), the soil MC was found to be about 12% points lower and was not dependent on the tillage system. After heavy rainfall, which occurred at the end of the first half of May (Fig. 1), the MC of the topsoil again reached a very high level for the last measurement date (17 May), when no significant influence of the tillage system on this parameter was found.

Soil T at 0-10 cm, as measured on five occasions (from 17 March to 17 May) during the growing season, did not differ statistically between the tillage systems except on one occasion on 17 April when the T value was found to be lower under CTS (10.39°C) than ST (10.69°C), ($p \leq 0.05$). Under both tillage systems, the lowest soil T was recorded on 17 March. The difference between the minimum and maximum soil T during the measurement period was lower under CTS (4.55°C) than ST (4.99°C). This may be indicative of the higher thermal stability occurring under CTS.

4. DISCUSSION

4.1. Temporal variations in soil physical properties

Our study showed that within a few days after all heavy precipitation events (27.03; 01.04; 09.04; 15.04; 25.04; 08.05 and 11-16.05), the SMT was found to be around 10 kPa (field-water capacity) or slightly lower (higher soil MC) irrespective of the tillage system used and the depth. In the following periods without precipitation, the trends of the temporal changes in SMT for the two tillage systems were predominately determined by temporal variations in precipitation while the scope of the changes was different. For example, in the period between 21 and 24 April, some days after the heavy precipitation event, the SMT increased to a greater extent under CTS than ST. This may be the result of a greater than 25.5% wheat dry biomass at this time under CTS as compared to ST (443 *vs* 353 g m^{-2}).

Similar responses were also recorded on other occasions during the growing season (data not shown). Increased water use under CTS as compared with ST may be further favoured by the greater (volumetric) water content at field-water capacity (37.0-38.2 *vs* 33.9-37.2) (Table 1). Furthermore, the greater wheat biomass under CTS is related to the canopy and leaf area index and may contribute to a higher SMT value by increasing the extent of the interception of the precipitation (Kang *et al*., 2005; Liu *et al*., 2022). It is worth adding that the greater SMT value in CTS than in ST soil occurred despite the presence of crop residues that reduce the rate of water evaporation and increase water infiltration by improving the soil structure and reducing the crusting rate (Subbulakshmi *et al*., 2009). The interpretation above implies that higher biomass production and the associated water use was the dominating factor in controlling seasonal variations in SMT for the examined tillage systems. In contrast to the SMT measured at a depth of 15 and 30 cm, the measurement of soil MC in the 0-10 cm layer indicated the generally better MC of this soil layer under CTS as opposed to ST conditions on some dates, which was even statistically confirmed on 17 March. However, also at a depth of 15 cm, a higher soil MC (lower SMT) was noted at this time (Fig. 1). The tendency towards a more favourable MC of the topsoil in the CTS on 2 May resulted from the occurrence of a modest rainfall at that time (approx. 2 mm), which increased the MC of the topsoil, but did not significantly affect the SMT at a depth of 15 and 30 cm.

Various probes are used in the study of soil moisture dynamics. TDR probes, which are calibrated in terms of the % of volume moisture, are commonly used. An experiment conducted by other authors with the use of TDR probes (Gałęzewski *et al*., 2023) confirms the results of the research presented in this manuscript concerning the relationship between precipitation and soil MC. In the studies cited, soil MC in the traditional (ploughing) and strip-till systems was compared, and it was found that the results obtained are not consistent with our own results. The authors proved that in strip-till, for most of the plant growth period, the soil MC was higher than in plough tillage, and only at the end of the vegetation period were these relationships changed. The discrepancy between the compared results is most likely the result of the fact that the plant biomass in both the strip-till and ploughing system is comparable, and in our own research in CTS this value was found to be much higher than in ST. It should also be taken into account that the TDR method is not selective for water contained in plant roots, unlike the measurement of the matrix potential (Gałęzewski, 2020).

Our research confirms the well-known negative correlation between soil MC and PR (Souza *et al.,* 2021; Subrahmaniyan *et al*., 2023; Wilczewski *et al*., 2015). A comparison between Figs 1 and 3 indicates that a greater SMT (lower MC) under CTS was reflected in a higher PR value. This is clearly visible during measurements conducted at the beginning of May (following heavy precipitation) when a greater SMT value was measured under CTS as compared to ST and resulted in PR > 2 MPa which has been reported to limit root elongation (Whalley and Bengough, 2013; Colombi *et al*., 2018). However, in this period (which is different from the other periods) higher PR values were found in the layers with a depth of 5-15 cm than in the 15-30 cm layer. These results are related to the lower sensitivity of the deeper soil layers to periodic rainfall deficiency, as described above. Therefore, the PR in the 15-30 cm deep layers was only slightly higher in this period than at the other measurement times, while in the 0-15 cm depth, it was much higher.

4.2. Effect of the tillage systems used on soil organic matter

An increase in the level of soil organic matter (SOM) is one of the most common research goals concerning reduced tillage, crop residue management and diversified cropping systems (Poeplau and Don, 2015; Farmaha *et al*., 2022). This is due to the fact that SOM improves crop productivity by increasing soil water retention capacity (Bolinder *et al*., 2020). The SOM content is of particular importance in the semi-arid Mediterranean regions that are predominantly not conducive to the build-up of soil organic C and are vulnerable to its loss (Aguilera *et al*., 2013, Musto *et al*., 2023). Our results have shown that the adoption of CTS significantly ($p<0.05$) increased the amount of topsoil organic matter as compared to ST (Fig. 2). This increase may be the result of the synergistic effects of reduced soil disturbance and the decomposition of organic matter (Du *et al*., 2022) along with the inclusion of cover crops in crop rotation and the incorporation of the crop residues. This explanation may be supported by the research of Bai *et al*. (2019) which indicates that carbon sequestration under no-tillage decreased when crop residues were removed. Thus, the adoption of CTS in the semi-arid region used in the study will help to improve both soil water retention and its availability to plants which are the most limiting factors affecting crop production in the study of the semi-arid area (Musto *et al*., 2023). Another benefit of the increase in SOM content under CTS is the reduced difference between the maximum and minimum soil T as compared to ST (4.55 *vs* 4.99°C) thereby indicating a greater buffer capacity against the extremes of T and resilience in the face of the adverse effects of progressive warming (Francaviglia *et al*., 2023). The importance of these results may be highlighted by the fact that SOM content is a relatively stable soil property and therefore it may prove to be useful in long-term strategies aimed at *e.g*., increasing soil quality by improving soil biodiversity, aggregation, infiltration, and the minimization of erosion losses (Hessel *et al*., 2022; Francaviglia *et al*., 2023) as well as greenhouse gas (GHG) emissions in order to mitigate the effects of global climate change (Hussain, 2021; Jayaraman and Dalal, 2022).

Overall, the results indicate that CTS has the potential to improve SOM accumulation, water-holding capacity and biomass production through reduced tillage along with appropriate crop residue management. Therefore, CTS is a promising practice in terms of soil quality and crop productivity in a highly variable semi-arid Mediterranean environment with soils that are predominantly of relatively low organic matter content (Gómez-Sagasti *et al*., 2018; Musto *et al*., 2023).

5. CONCLUSIONS

The results of this study showed the following:

1. Soil moisture tensions were similar shortly after heavy precipitation (5 to 10 kPa) irrespective of the tillage system used and the soil depth at which the measurement took place, while with the increasing length of the period without precipitation (using the last precipitation incident as the starting timepoint), the soil moisture tensions increased to a greater extent under conservation tillage shallow as compared to standard tillage. This response was attributed to greater biomass production under conservation tillage shallow as compared to standard tillage. The temporal changes in soil moisture tension in response to precipitation were less sensitive at the 30 cm than at the 15 cm depth.

2. The adoption of conservation tillage shallow as compared to standard tillage favourably increased the sequestration of soil organic matter and field-water capacity and decreased the difference between the minimum and maximum soil temperature.

Conflict of interest: The authors declare no conflict of interest.

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