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Rainfall induced changes in soil moisture: A comparative study of conventional and strip tillage

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Abstract: Strip tillage is a very popular form of conservation tillage that is used in places with a higher risk of soil erosion. It is commonly accepted that strip tillage reduces the effects of water erosion; however, the exact way this effect is produced is very hard to quantify. This study focuses on the way strip tillage influences soil moisture and the way it changes with different intensities of rainfall, in comparison with conventional tillage. This study was conducted near Petrovice, Středočeský kraj, Czechia, over the course of four years (2021–2024). The conditions of all four test sites were comparable, both in terms of slope and soil type present. The soil moisture of strip tillage in a depth of 15 cm was changing differently in comparison with conventional tillage. During lower intensity rainfall events, the soil moisture of the strip tilled plot changed significantly less in comparison with conventional tillage. On the contrary, when more intense precipitation occurred, the soil moisture in the strip-tilled plot responded with significantly higher changes in comparison with conventional tillage. Soil drying after precipitation was also studied, with the speed of drying of strip tillage being higher than that of conventional tillage. These findings help better understand the changes strip tillage introduces into the soil and to the crops it is used with.

Keywords: conservation technologies; maize; soil conservation; soil water content; TMS sensor

The importance of agriculture, especially in the current state of the world, needs no introduction. It is therefore very important to continuously re-evaluate the currently used technology, and to attempt to work on gradually improving our practices and our approaches to the many problems it has been facing. This study is focused on the effects of one of the more widely adopted soil conservation methods, which is strip tillage. Strip tillage is often used in Czech agriculture, among other reasons, due to the high percentage of agricultural soil being threatened by water erosion (up to 50%) (Janeček et al. 2012). It is commonly used as a soil conservation method, particularly while cultivating maize on steeper slopes, where the usage of some kind of soil conservation technology is mandatory pursuant to state regulations.

Strip tillage is one of the many commonly used forms of conservation tillage, along with reduced tillage and no tillage. No-tillage systems are per-

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haps the simplest form of soil conservation tillage. A typical no-till system is achieved by cutting a narrow line in the soil, into which seeds are later deposited. Reduced tillage (also referred to as minimum tillage) consists of undertaking the minimal possible number of agricultural operations, in order to cause as little disturbance to the soil as possible (Roberts et al. 2025). Strip tillage lies somewhere in between the two aforementioned methods. A strip-tilled system utilises tilled strips of various thickness for crop planting, with untilled inter-rows in between them, on which crop residues are left. These untilled inter-rows provide various benefits, such as increased dry bulk density, better aggregate arrangement and generally healthier soil (Pöhlitz et al. 2018). Additionally, in comparison to conventional tillage, a field cultivated using strip tillage will be much less susceptible to water erosion due to its inter-rows being covered by crop residues, and its mean long-term soil loss will therefore be much lower (Laufer et al. 2016). As an example of the magnitude of this effect, observed in conditions similar to this study's, a value of 0.40 t per ha/year was recorded on a strip-tilled field, compared to 2.96 t/ha/year on a field cultivated using conventional tillage (Menšík et al. 2020). Multiple other studies (Ryken et al. 2018; Procházková et al. 2020; Prasuhn 2022) have come to a similar conclusion, so the effect of strip-tillage on soil erosion is clearly beneficial. The effects of strip tillage on other soil properties can vary, as there are many influences at play.

Regarding maize yield, strip tillage is thought to be a compromise between no tillage and conventional tillage, offering both soil conservation and good yield. In comparison with conventional tillage, the yield of a strip tilled field will generally be unstable, often lower (Różewicz et al. 2024; Sha et al. 2025), but this reduction in production capability is offset by requiring less management, and therefore fuel cost (Celik et al. 2013). The economic benefits of this approach were examined in depth in multiple studies and were found to be acceptable (Akplo et al. 2025). The effect of strip tillage on other soil properties is highly varied and depends on many factors, but most importantly on the mean annual temperature and cropping system being used (Dou et al. 2024).

Soil temperature is an important factor which plays a large part in the early growth rate of crops. The overall soil temperature of a strip-tilled field is generally lower, owing mainly to the inter rows being covered with plant residues (Sainju et al. 2025), and therefore intercepting some solar radiation and acting as an insulator (Gałęzewski et al. 2022). A further temperature stratification effect often appears, with the inter-rows being colder on average than the in-rows (Różewicz 2022). Increased temperature in the in-rows occurs due to the soil there being tilled and therefore its surface being more susceptible to changes in air temperature.

The core focus of this study is soil moisture, which is definitely one of the more variably influenced soil properties. In general, strip tillage has a positive effect on soil moisture (Jaskulska et al. 2020), thanks to the plant residues in the inter-row reducing the incoming solar radiation and therefore reducing soil temperature and evaporation. This study is focused on further examining the changes in soil moisture content related to different intensities of rainfall and the implications these may have on some other properties. In general, the frequency of high-intensity torrential rains is increasing each year, and it is prudent to understand the way strip tillage changes the soil moisture regime, especially in regard to such adverse conditions.

MATERIAL AND METHODS

Study location and test site parameters. The study took place over the course of 4 years in central Bohemia, in close proximity to Petrovice, Středočeský kraj, Czechia, 49°33'30.28''N, 14°20'13.83''E. The on-site mean annual temperature reached values of 7–8 °C, and the mean annual rainfall was about 550–650 mm. The typical landscape of the region consists of frequent smaller hills, reaching up to 580 m a.s.l., with generally little flat land. Soil samples were collected from each test field to confirm the soil type and to provide values for sensor calibration. Eubasic Cambisols were determined to be the dominant soil type on all test sites, belonging to the hydrological B group. Based on the collected soil samples and their subsequent analysis, soil properties on all the test fields are very closely comparable; thus, the conditions of the test fields can be considered similar.

A field that matched the requirements was selected each year (slope under 20%, southern or southeastern exposition, similar soil quality) and a small area of it was converted to a test field. The test fields consisted in part of conventionally cultivated maize and of a conservation tillage variant (strip-tilled into intercrop residues). The intercrops were planted by the end of August, then later in the spring, prior to maize being planted,

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these were sprayed with a desiccant agent, and the soil was strip tilled using a AGRISEM STRIPCAT II strip-till machine (AGRISEM SA, France), creating a pattern of in-rows of 25 cm of width and inter rows of 75 cm of width. Later, after maize germination, dataloggers were deployed to collect measurements of soil temperature and soil moisture and were kept on-site for the duration of the vegetation period. The dataloggers were collected before harvest.

Data collection. For data collection, TMS-4 sensor-dataloggers (TOMST s.r.o., Czechia) were used. A TMS-4 datalogger contains a volumetric soil moisture sensor, several temperature sensors, a battery, a data collection port and a shield cover. Its main benefits are its size, its longevity and ease of implementation. The sensors are simply inserted into the soil at a point of interest and then left to operate. The stored data can be extracted from the datalogger while it is deployed, if appropriate caution is exercised. The dataloggers can be set to collect values at a customizable time interval; in our case, an interval of 10 min was chosen. A variant of this datalogger is also available that can be buried in order to facilitate measurements from a higher depth.

Within every variant of tillage currently present on the test field, a location was selected for data gathering, and TMS-4 dataloggers were deployed there. The distance between the data collection points of different variants was kept to a minimum and amounted to approximately 4 m. Each variant of tillage contained two surface dataloggers (Figures 1 and 2). Special care was taken to orient the dataloggers in such a way that water would not accumulate on the sensors, which is a common issue of the buried variant of the datalogger. The sensors were then left on site over the maize vegetation period and were later pulled out a few days before harvest. This procedure was repeated each year over the course of four years. After each repetition, the data were downloaded from the dataloggers and processed via a procedure provided by the manufacturer. Each TMS-4 datalogger was calibrated separately, according to instructions released by the manufacturer (Wild et al. 2019). This study focuses on surface soil moisture, and the values used throughout were acquired at a depth of 0–15 cm.

Design of the experiment. For the purposes of this study, and in order to better evaluate the changes in soil moisture of different tillage variants and the way these values respond to different kinds of rainfall events, rainfall events were divided into two groups: torrential rainfall events and non-torrential rainfall events. The criteria for the two distinct rainfall event types were based on the criteria used to determine erosive significance of rainfall, while calculating the R-factor of USLE (Wischmeier & Smith 1978). This is done in order to select rainfall events that cause surface runoff due to their intensity being higher than the infiltration speed of the soil. For a rainfall event to be considered erosively significant, the following conditions must be met: the total rainfall amount of the event must exceed 12.5 mm, from the previously listed 12.5 mm, a total of 6.25 mm must be accumulated within less than 15 min; the event must be separated from other rainfall events by at least 6 h. This way, a series of non-torrential rainfall events was selected.

In place of naturally occurring runoff inducing rainfall events, rainfall simulations were conducted

Figure 1. A pair of installed TMS-4 dataloggers prior to maize germination, strip-tilled plot

Figure 2. TMS-4 dataloggers during the maize vegetation period, strip-tilled plot

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using a field rainfall simulator. The rainfall simulator covers a total space of 21 m^2 and produces a rainfall event that equates to an intensity of about 55 mm/h over the course of 1 hour. This simulated rainfall was then conducted at each measuring site with repetitions. During the experiment, the volume of surface runoff was measured, and samples of it were collected. On the strip-tilled plot, surface runoff occurred in much lower quantities and much later compared to the conventionally tilled plot.

Statistics and experiment. The focus of this study is understanding and quantifying the effect of different intensities of rainfall on soil water content, particularly in a very short time frame. Attention was paid to how quickly and by how much soil moisture changes during and after the rainfall event. With that in mind, multiple points of interest during each event were selected and used to divide the rainfall event into three phases. First point of interest was the soil water content value prior to the start of the rainfall event. As a second point, the value with peak soil water content during the event was selected. The remaining data points were based off of the second data point, those being intervals of 12, 24 and 36 h from the peak moisture data point.

By using the aforementioned data points as boundaries, each rainfall event was divided into two phases, based on soil moisture changes, namely a saturation phase and a drying phase. Our aim was to determine whether changes in the saturation and drying effect size varied among different tillage methods, and further, whether the difference is significant enough to have an effect on other soil properties. This way, both the simulated (torrential) and the non-torrential rainfalls were analysed, with the aim being to spot potential differences between how soil moisture reacts during more intense rainfall, for example, when surface runoff occurs, compared to less intensive rainfall events. The difference (in %) of soil moisture recorded at the selected point in time prior to the start of rainfall and the peak soil moisture recorded during the rainfall event was then used in the statistics. Due to the plots being located right next to each other, the conditions and outside influences are considered the same on both plots. This allowed us to consider the two studied plots to be the same, and, for the purpose of uncovering the potential significance of the observed differences, a paired t-test was used. The chosen significance value was set at $P < 0.05$.

RESULTS

Results of the soil moisture measurements are divided into three sections, each corresponding to its respective scenario. The first two sections refer to the saturation phases of rainfall events, while the third is dedicated to the drying phase of the events. In each of the first two sections, attention is paid mostly to the differences between the mean soil water content values, meaning the soil water content (SWC) value before the start of precipitation, and the highest recorded SWC during the rainfall event. For the purpose of statistics, multiple points at set time intervals were selected within the saturation phase. The third section concerns itself with the speed of drying of the tillage variants, its data row starting at the point of highest SWC and then continuing in 12-h intervals, until 36 h are reached. The dataset for the third section had to be reduced, due to frequent, otherwise insignificant rainfall events occurring within the selected time frame. As a result, the statistics portion of the third section contains values from both torrential and non-torrential rainfall events. The values displayed in the tables are mean values, obtained from averaging the values of all the rainfall events used in each respective category.

Saturation phase of torrential rainfalls. Results show soil moisture values recorded at a depth of 15 cm. Table 1 displays recorded soil moisture values from torrential rainfalls between the years 2021 and 2024. During the year 2024, no torrential rainfall that would fit the parameters occurred on the test site; therefore, it could not be used. Values displayed in Table 2 show the mean values of volumetric SWC of each tillage variant, before a torrential rainfall event took place, and after reaching peak moisture as a result of torrential rain. Next, the table displays

Table 1. Soil moisture changes during torrential rainfalls, divided by years

Tillage variant	SWC mean in 15 cm (%)	
	before the rainfall event	peak during the event
CT (2022)	30.5	41.2
ST (2022)	18.8	36.3
CT (2023)	13.7	30.6
ST (2023)	3.4	32.4

SWC – soil water content; CT – conventional tillage; ST – strip tillage

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Table 2. Soil moisture changes during torrential rainfalls

Tillage type	Sample size	SWC mean in 15 cm (%)		*Xd*	SD	*P*
		before the rainfall event	peak during the event			
Conventional tillage	8	22.1	34.3	4.772	3.376	0.0052**
Strip tillage	8	11.0	35.9			

SWC – soil water content; *Xd* – average of differences; SD – standard deviation; $P < 0.05$

results of the paired *t*-test, namely the average difference (*Xd*), standard deviation (SD) and the *P*-value of the test.

The average change of moisture as a result of torrential rainfall of the conventionally tilled plot amounted to 12.2%, whereas on the strip-tilled plot it reached the average value of 24.9%. A paired *t*-test was conducted to verify the presence of a statistically significant difference. The *t*-test observed a large statistically significant difference among the changes in soil moisture during the saturation phase of the tested tillage variants with a *P*-value of 0.005, the SD was 3.376, and the *Xd* was 4.772. The soil moisture of the strip tilled plot increased dramatically more in comparison with conventional tillage after being subjected to torrential rainfall.

Saturation phase of non-torrential rainfalls. Table 3 shows soil moisture values that were recorded during non-torrential rainfalls over the years. The values displayed in Table 4 illustrate the same characteristics as Table 2, this time recorded during non-torrential rainfalls. The mean soil water content in 15 cm before the start of the rainfall event and the peak mean soil water content during the rainfall are shown, alongside results of the *t*-test, those being the *Xd*, SD and the *P*-value of the test.

During the saturation phase of non-torrential rainfalls, the changes in soil moisture were much lower, with the average difference being 6.8% for the conventionally tilled variant and 1.9% for the strip-tilled variant. The soil moisture values were validated with a paired *t*-test, which uncovered a statistically significant difference between the two variants, with a *P*-value of 0.0277. The observed effect was of medium size. The SD recorded here amounted to 5.164, and the *Xd* reached –2.752. During non-torrential rainfalls, the results were different, *i.e.* conventional tillage reacted more to the incoming rainwater, compared to the strip tilled plot.

Drying phase. In Table 5 are shown the results of measuring soil moisture during the drying phase of rainfall events. The dataset used here contained both torrential and non-torrential rainfall, with additional selection taking place, due to smaller rainfall events often taking place during the measured interval (36 h), thus rendering the measured sequence unusable. Displayed in the table on the left side are the average maximum soil moisture recorded at a depth of 15 cm during rainfalls, and the averages from the three subsequent 12-h intervals. Further on the right

Table 3. Soil moisture changes during non-torrential rainfalls divided by years

Tillage variant	SWC mean in 15 cm (%)	
	before the rainfall event	peak during the event
CT (2024)	22.9	31.9
ST (2024)	21.6	24.1
CT (2023)	22.7	29.4
ST (2023)	19.9	23.7
CT (2022)	17.5	24.4
ST (2022)	14.1	15.9

SWC – soil water content; CT – conventional tillage; ST – strip tillage

Table 4. Soil moisture changes during the saturation phase of non-torrential rainfalls:

Tillage type	Sample size	SWC mean in 15 cm (%)		*Xd*	SD	*P*
		before the rainfall event	peak during the event			
Conventional tillage	20	20.7	27.5	–2.752	5.164	0.0277*
Strip tillage	20	18.6	20.5			

SWC – soil water content; *Xd* – average of differences; SD – standard deviation; $P < 0.05$

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Table 5. Soil moisture changes during the drying phase

Tillage type	Sample size	Mean max SWC in 15 cm	Mean SWC in 15 cm			*Xd*	SD	*P*
			12 h after max	24 h after max	36 h after max			
		(%)						
Conventional tillage	32	31.4	29.8	26.1	25.3	2.92	2.575	0.002**
Strip tillage	32	39.7	34.1	26.3	24.9			

SWC – soil water content; *Xd* – average of differences; SD – standard deviation; $P < 0.05$

side of the table, a statistics summary is also shown with *Xd*, SD and *P*-value of the *t*-test being shown.

During the drying phase, soil moisture was recorded every 12 h. This was done mainly to understand the speed of the drying process. The biggest changes are noticeable between the 12 and 24-h intervals, a difference of up to 8.225 % observable on the strip-tilled plot, compared to a smaller, 3.698% on the conventionally tilled plot. The values were also subjected to a paired *t*-test, which discovered a statistically significant difference in drying rate among the different types of tillage. The *P*-value of the test was 0.002, with a SD of 2.575 and an *Xd* of 2.92. The observed speeds of drying show the strip-tilled plot to be initially drying out faster than the conventionally tilled plot (Figure 3).

DISCUSSION

We observed a difference in the changes of soil moisture, based on the intensity of the rainfall event that took place. During torrential rainfall, soil moisture was increased by 12.2% on the conventionally tilled plot, compared to 24.9% on the strip-tilled plot. During non-torrential rains, this change was only 6.8% and 1.9% respectively. Based on these results, different tillage variants seem to react differently to rainfall based on its intensity. However, these results could be in a large part dependent on the soil type present at the site, and importantly, the type of crops and intercrops used in the system. It is probable that the plant residue cover is responsible for a large part of the observed difference, due to its

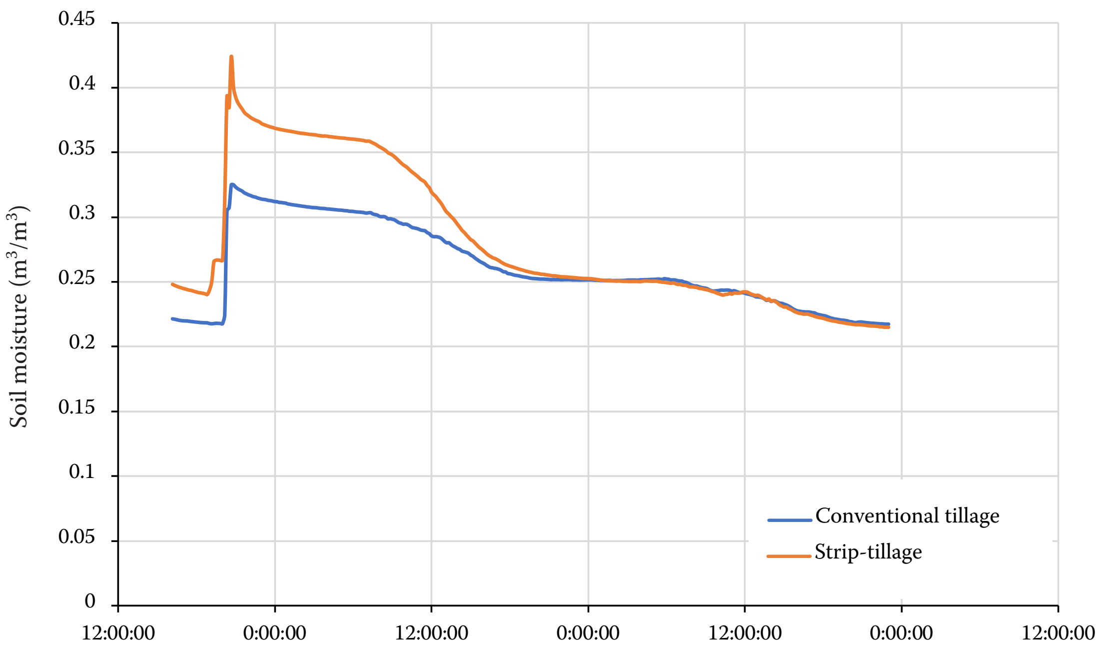

Figure 3. Soil moisture during the drying phase of a selected rainfall event, the strip-tilled plot reduces its moisture significantly faster, especially during the initial periods

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intercepting a set amount of water during each rainfall event. The less intensive rainfall events would therefore be intercepted by this crop residue cover in greater part than the more intensive torrential rainfalls, and would in turn cause a smaller change in soil moisture. Additionally, in later stages of the maize growth period, the inter-row width of 75 cm is narrow enough for maize leaves to overshadow a large percentage of the surface area, thus providing an additional rainwater interception source. This could prove beneficial in times where less intensive rainfalls are more plentiful and could result in overwatering the crops, as some conservation tillage methods can lead to excessive soil water, as some studies show (Ghaffardzeh 1997).

Conflicting observations were made by Jaskulski in 2019, who focused on the zonal effect caused by the imperfections of strip-till and sowing machines, and the spatial differences occurring in the soil cultivated with the use of them. Here, the cultivated part of the soil was the zone with the highest soil water content change, the value after rainfall being 20.4% in the in-row, 16.3% in the inter-row and 18.5% on the ridge. The author believes this to be a result of the beneficial surface properties of the cultivated and therefore very loose soil, in comparison to the uncultivated inter-row, which also developed a ridge. Additionally, after a 5-day period with no rains, the uncultivated inter-row contained the highest soil water content, thanks to the compacted and uncultivated soil present. The recorded SWC after 5 days amounted to 16.7% in the in-row, 19.4% in the inter-row and 11.3% on the ridge. These values are not dissimilar from ours; however, the different natures of both studies will influence the results. Matula (2002) focuses on the relations between water infiltration and conditions of the top layer of soil and, among other things, brings attention to another important factor which influences the infiltration rate, that being the water content present in soil before precipitation starts. The higher the initial moisture is, the slower the infiltration rate will be (Wei et al. 2022). Another key issue brought up in the aforementioned study is the level of compaction of the topsoil layer, which is also relevant to our findings. The untilled soil in the inter-row of the strip tilled plot can, over time, become more compacted and thus reduce the infiltration rate, whereas the conventionally tilled, more often disturbed surface layer, will improve the infiltration rate during less intense rainfalls, and therefore remain more saturated over time. This could result in the tilled soil not being ready to accept large amounts of water, and could also allow surface runoff to occur more frequently. However, that does not directly equate to a higher soil erosion rate, as higher soil moisture, up to a certain point, reduces the soil erosion rate (Moragoda et al. 2022). Studies such as Larionov et al. (2014) discovered a relationship between soil moisture and erodibility, with the lowest erodibility found at a soil water content of 22–24%. The soil moisture of the conventionally tilled plot was in general closer to these values and could possibly benefit more from this effect.

The results of the third part of the experiment showed a difference in drying of soil after reaching maximum saturation during select rainfall events. The dataset here differs from the previous two segments, due to the high frequency of rainfall during the experiment period. Some rainfall events had to be excluded, as there was not enough time without precipitation after the initial event. This is also why the studied period was set at 36 h, as considering a longer time would in turn shrink the dataset even more. Such rearrangement explains the different soil water content values. By using the maximum recorded soil water content reached during rainfall as a starting point, the difference in soil drying speed can be visualised. While soil moisture reaches similar values within 24 h from precipitation (a difference of 0.2%), the initial speed of drying is very different. Within the first 12-h period, the conventional tillage plot's moisture decreased by 1.6%, compared to the 5.6% change on the strip tilled plot. Such a high drying speed of the strip-tilled plot could be explained as a result of the initially very high percentage of soil moisture. Idso et al. (1974) describes the first of the three stages of soil drying as being very dependent on atmospheric conditions and lasting at least 24 h after precipitation, but possibly longer. The duration of this stage varies based on the current evaporative demand. As the soil water content in our case is very high, the duration of this phase could be increased. This extension could be responsible for the difference in soil drying speed in the later phases, such as the 12–24-h interval. In this interval, the strip-tilled plot reduced its soil moisture by 7.8% almost twice as the conventionally tilled plot, where the value reduced only by 3.7 %. Only after 24 h does the speed of drying decrease to a respective 0.8%/12 h and 1.4%/12 h, over the course of the third 12-h period. Various other factors are at play while determining the speed of drying, with the textural differences of different

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soil layers playing an important role. Li et al. (2020) focuses on the effect of the texture of the top soil layer on soil moisture. Soil that is texturally different, with an overlaying coarse layer and an underlaying fine layer will exhibit different speeds of evaporation. On a strip-tilled plot, with the interrow remaining untilled for longer periods of time, a slight stratification effect could be present, and influence the speeds of evaporation and soil moisture in general.

CONCLUSION

Strip tillage in this case influenced the soil moisture regime in comparison to conventional tillage. Less intense precipitation events caused a smaller change in soil moisture of the strip-tilled plot compared to conventional tillage. Conversely, more intense rainfalls had a greater effect on the soil moisture of the strip-tilled plot than on that of the conventionally tilled plot. These results indicate that strip-tillage influences water infiltration and soil water content regimes, potentially reducing surface runoff in comparison to conventional tillage. Along with its other benefits in terms of soil conservation, this helps strip tillage to better manage the precipitating water in higher intensity rainfall events, thereby aiding it in limiting water erosion. The soil drying speed of the strip tilled plot was also higher in comparison with conventional tillage. Faster drying and less soil moisture gained from low-intensity rainfall events could also account for the better infiltration of precipitation coming from larger, more intense rainfall events. The obtained results provide an insight into the short-term soil moisture changes during precipitation in strip-tilled soil and could help us to comprehend more thoroughly the multitude of ways by which strip tillage reduces water erosion.

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