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Evaluation of runoff and soil erosion under conventional tillage and no-till management: A case study in northeast Italy

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ABSTRACT

Conservation agriculture, and in particular no-till systems, generally yield improvements in both soil characteristics (e.g. structure, and water holding capacity) and soil processes (such as runoff and hence erosion). Nevertheless, during the first years of no-till, the soil is prone to compaction due to the poor structure, missing ploughing activities, and passage of tractors and machinery, thus favouring surface runoff and soil erosion. Little information exists about the effect of no-till when applied during the transition period from conventional to conservation agriculture. This study aimed at analysing runoff and soil erosion in a non-tilled field in comparison with a tilled field during the transition period. The study was conducted at the Padova University Experimental Farm, in northeast Italy. Six sub-plots (2.5 m × 5 m) were established, three in a tilled field (CT plot) and three in a non-tilled field (NT plot). Each sub-plot was equipped with a runoff water collection system. Runoff was monitored during two sampling seasons: from May to October 2017 and May to September 2018. Runoff water volume was measured at each rainfall event, and the amount of sediment was quantified by drying the runoff samples. This technique is simple and inexpensive and suitable to be applied also in rural areas with inadequate infrastructures and economic resources. Two indices, runoff reduction benefits (*RRB*) and sediment reduction benefits (*SRB*), were computed. During the monitoring period, 24 runoff events occurred. NT practices coincided with reductions of over 50% in runoff volumes and 50% to 95% in sediment losses. Only the runoff event just after the CT soil harrowing produced a significantly lower runoff and sediment loss in CT than in NT field, due to the effect of soil tillage on surface roughness and rainfall infiltration. The average sediment concentration in NT was only 47% of CT. The *RRB* and *SRB* values confirmed a reduction in runoff and sediment loss in the NT compared with the CT plot, but *SRB* was greater than the *RRB*, indicating that the no-till regime showed a better control of sediment loss than it did the runoff amount. The reduced runoff and sediment yield in the NT plot could have important on-site benefits in terms of both sustainable soil management and surface water quality.

1. Introduction

Conservation agriculture was recently promoted in the European Union's Common Agricultural Policy (CAP, Rural Development 2014–2020; Basch et al., 2011) as a means of tackling primary environmental problems, such as the increasing levels of atmospheric carbon dioxide (CO_2), decreasing biodiversity, and limited water availability (Armengot et al., 2015; Bouma and McBratney, 2013). This approach consists of practices aimed at achieving sustainable and profitable agriculture through the application of three fundamental principles: (1) minimising mechanical soil disturbance (reduced tillage or no-till), (2) maintaining permanent soil cover by using crop residues and cover crops, and (3) adopting crop rotations (Hossain, 2013). Limiting mechanical soil disturbance in crop management is a main factor in enabling soil structure and organic matter to be maintained. The reduction or elimination of tillage enables the minimal soil disturbance and permanent soil cover to be achieved (Shahzad et al., 2016; Tarolli et al., 2019). The benefits for soil and water conservation have been well documented in the literature (Bogunovic et al., 2018; Jordán et al., 2010; Nyssen et al., 2008; Sun et al., 2015; Wang et al., 2015). Positive outcomes worth mentioning include the maintenance of a stable soil structure and biological activity, improvements in soil

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fertility and micro-climate due to permanent organic soil cover, water infiltration enhancement, and reduction of runoff and soil erosion (Berger et al., 2010). Higher infiltration rates can in turn reduce surface water losses from fields and improve water holding capacity (Thierfelder and Wall, 2009). Several studies have quantified how conservation tillage practice reduces runoff and soil erosion (Armand et al., 2009; Jia et al., 2019; Leys et al., 2010; Maetens et al., 2012; Montgomery, 2007; Shipitalo and Edwards, 1998; Wang et al., 2015). To fully appreciate the benefits of conservation agriculture for soil and water conservation, the soil has to be "mature", a state it achieves by undergoing a transition period from conventional to conservation agriculture, lasting approximately five to seven years, during which non-tilled soil is gradually subjected to a series of changes and adaptations to the new management system (Hobbs et al., 2008). The transition period presents some major difficulties. The lack of mechanical weed control means that weed abundance and density may be higher than in a conventional system, and weed management relies mainly on chemical inputs (Armengot et al., 2015; Knowler and Bradshaw, 2007). Furthermore, owing to its low organic matter content and poor structure, combined with the effect of the missing ploughing activities and the passage of heavy tractors and machinery, the soil tends to be prone to compaction (Piccoli et al., 2016), resulting in a potential increase in surface runoff and soil erosion during the transition period compared with conventional management. Soil compaction, combined with intensified herbicide use, dramatically increases the risk of herbicide loss in runoff and surface water contamination (Cessna et al., 2013). Thus, the vulnerability of non-tilled (NT) soil to runoff and soil loss during the transition period plays a critical role in both the agricultural and environmental sustainability of this system.

To our knowledge, little information exists about the effect of no-till on runoff and soil erosion during the transition period from conventional to conservation agriculture, where changes in soil properties following the introduction of no-till are not yet fully developed. Therefore, this study aimed at analysing runoff and soil erosion processes (and the complex interrelation among factors that might affect such processes) occurring in a non-tilled field during a transition period from conventional to conservation agriculture in comparison with a tilled (CT) field. The years of the study were the third and the fourth years of conservation management for the NT field. The main novelty of this work is that the focus of the study is precisely placed on the transition period from conventional to conservation agriculture, regarding which the existing knowledge suggests a potential increase in the vulnerability of the soil to runoff and soil erosion compared to the conventional tillage. The promptness of improving some mechanisms of soil protection against runoff and erosion after tillage abandonment could have significant consequences for the vulnerability of drought and the risk of pollution of surface waters with sediment, pesticides and nutrients. The gained information will help in filling the current gap of knowledge about the consequences for runoff and soil loss due to the soil conversion from conventional to conservation agriculture.

2. Materials and methods

2.1. Site information

The study was conducted during 2017 and 2018 at the Padova University Experimental Farm in the Po Valley, Northeast Italy (45°12′N, 11°58′E, altitude 6 m a.s.L.) (Fig. 1).

The local climate is sub-humid with a mean annual temperature of 15.6 °C. Annual rainfall in 2017 was 518 mm with a total of 62 rainy days; the wettest month was September (146 mm rainfall) and the driest was February (7 mm). Annual rainfall in 2018 was 853 mm with a total of 89 rainy days; the wettest month was October (142 mm rainfall), and the driest was December (12 mm). Six sub-plots (each 2.5 m × 5 m) (Fig. 1) were established in spring 2017, three in a field managed under a conventional tillage regime (CT plot), and the other three in a field managed using conservation agriculture (NT plot) (Fig. 2). The NT field was rectangular (200 m × 35 m) and had managed using conservation agriculture since 2014. The CT field was also rectangular (235 m × 40 m). The slope was 2.7% for both NT and CT field. The two fields faced each other and were separated by a ditch. Each sub-plot was bounded on three sides by metal boards that were inserted 15 cm below-ground, with 15 cm protruding above the surface to prevent any splash effect or runoff flowing either out of or into adjacent sub-plots. Each sub-plot was equipped with a runoff water collection system with a 55 L tank. High volumes were collected from the CT plot in some runoff events during the first sampling season, so tanks on the CT plot were replaced by 100 L tanks in July 2018.

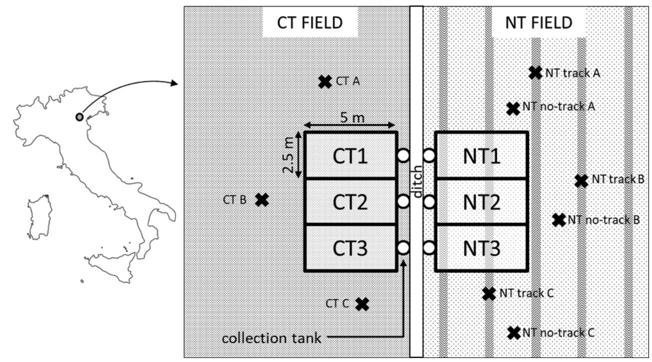

Fig. 1. Location map of the study area and layout of the six experimental sub-plots installed on the CT field (CT1, CT2, and CT3) and NT field (NT1, NT2, and NT3). The locations of the soil samples collected in CT and NT fields in November 2017 are also reported (sampling points are indicated with an x). Three samples sampling locations were selected on the CT field (CT A, CT B, and CT C), and six from the NT field, among which three on the track position (NT track A, NT track B, and NT track C) and the other three on the no-track position (NT no-track A, NT no-track B, and NT no-track C).

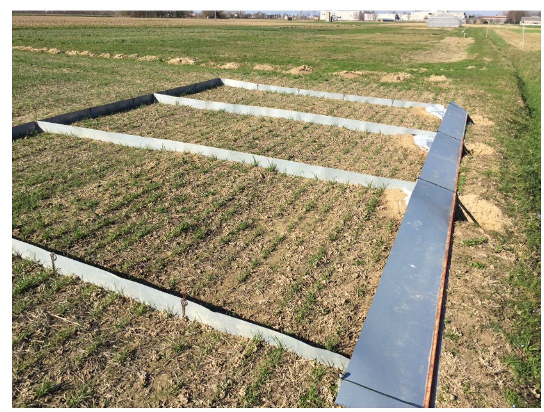

Fig. 2. Details of NT plots. The picture was taken in summer 2017 (photo by P. Tarolli).

Sub-soiling was performed in the CT field in September 2016, followed by harrowing at the end of October. In November 2016, both fields were sown with wheat, which was harvested in June 2017. In NT, crop residues of wheat were left on the field. In July 2017, the NT field was sown with soybean, which was harvested in October, leaving crop residues of soybean on the field. The CT field was ploughed to a 25–30 cm depth in November 2017, according to local practices. After ploughing, the CT field had a coarse cloddy surface that did not allow the installation of the runoff plots and the collection of runoff water, therefore the sampling was interrupted until the seedbed preparation. In November 2017, the NT field was sown with horseradish as a cover crop, which was terminated in April using a herbicide treatment. CT soil cultivation using a chisel was undertaken at the end of January 2018. Runoff water sampling was restarted in May 2018 when both fields were sown with maize. The CT field was harrowed before maize sowing. The maize was harvested in mid-September, and runoff water sampling was stopped at the end of October.

In the NT field, crop residues of maize were left on the field, whereas sowing was performed with specific equipment for sod-seeding which penetrate the layer of litter/crop residues and the soil, place the seed at a constant shallow depth, and pack soil around seeds.

In November 2017, before ploughing the CT field, soil samples were collected from both the NT and CT fields next to the runoff plots. Three sampling locations were selected on the CT and six on the NT field. Among the six sampling locations on NT field, three were on the no-track and three on the track position, the latter being the portion of soil affected by the passage of tractor wheels (Fig. 1). At each sampling location, two samples type were collected: disturbed and undisturbed. The disturbed soil samples were collected at 15–20 cm depth, then placed in a labelled plastic bag, sealed, and transported to the laboratory. The undisturbed soil samples were collected at 15–20 cm depth using cylindrical samplers (height, 7.0 cm; internal diameter, 7.2 cm). The cylindrical sampler was slowly driven into the soil with a hammer. Then, the soil around the cylinder was dug to withdraw the cylinder trying to lead a minimum perturbation into the inner soil. The two ends of the cylinder were closed with two thin wooden panels, and then the sample was placed in a labelled plastic bag, sealed, and transported to the laboratory. Disturbed soil samples and undisturbed soil cores were analysed at the Laboratory of Soil Hydrology of the Department of Agricultural Sciences, AFBE Division (University of Naples Federico II, Portici, Italy). Disturbed soil samples were air-dried, sieved at a particle diameter of 2 mm, and analysed to determine the soil texture (Gee and Or, 2002). Undisturbed soil cores were analysed to determine the oven-dry soil bulk density (*BD*), saturated soil water content (θ_S) (Topp et al., 2002), and saturated hydraulic conductivity (K_S) (Reynolds and Elrick, 2002).

2.2. Runoff sampling

The study was conducted under natural rainfall conditions. The weather station on the experimental farm, located 30 m from the plots with a rain gauge recording every 5 min, was used to measure rainfall events. Runoff was monitored during two sampling seasons, from the beginning of May 2017 to the end of October 2017 (first period) and from the beginning of May 2018 to mid-September 2018 (second period). During the monitoring periods, rainfall events were analysed to evaluate the relationships among rainfall, the soil hydrological characteristics, and runoff and erosion processes. For each rainfall event, we obtained the precipitation amount and duration, its maximum intensity at different time intervals (10, 30, and 60 min), and the cumulative precipitation (during the previous 7, 15, 30, and 45 days).

The chosen technique for measuring runoff volume and sediment concentration is rather simple and inexpensive. These characteristics make it suitable to be applied everywhere in the world, also in rural areas characterized by scarce infrastructure (e.g. in development countries), and where sophisticated instruments, trained personnel and the economic resources to measure runoff and sediment concentration are not available. The total runoff water volume collected in the tanks was measured for each rainfall event and, for the sediment analysis, three 0.5-L water samples were collected from each sub-plot and placed in aluminium bottles, homogenising the water and sediment. The samples were then transferred into plastic containers and placed in a dryer at 60 °C for 48 h. When all the water had evaporated, the samples were weighed to obtain the sediment yield for erosive events. Sediment concentration was multiplied by the runoff volume to determine the sediment yield from each sub-plot at each runoff event. The CT plot was chosen as the control group. Two indices were selected to assess the effects of the different tillage methods on runoff and sediment: 1) Runoff Reduction Benefit (*RRB*) in %; and 2) Sediment Reduction Benefit (*SRB*) in % (Wang et al., 2017; Zhao et al., 2014). The indices were calculated for each runoff event and for the entire study period, as follows:

$$\text{if } (R_{CT} - R_{NT}) > 0, \; RRB = 100 \times \frac{|(R_{CT} - R_{NT})|}{R_{CT}} \tag{1}$$

$$\text{if } (R_{CT} - R_{NT}) < 0, \; RRB = 100 \times \frac{|(R_{CT} - R_{NT})|}{R_{NT}} \tag{2}$$

$$\text{if } (S_{CT} - S_{NT}) > 0, \; SRB = 100 \times \frac{|(S_{CT} - S_{NT})|}{S_{CT}} \tag{3}$$

$$\text{if } (S_{CT} - S_{NT}) < 0, \; SRB = 100 \times \frac{|(S_{CT} - S_{NT})|}{S_{NT}} \tag{4}$$

where R_{CT} and R_{NT} are the runoff amount (mm) from the CT and NT plots, respectively, and S_{CT} and S_{NT} are the sediment loss amount (kg ha^{-1} $event^{-1}$) from the CT and NT plots, respectively.

These indices, as calculated in the Eqs. (1) and (3), provide the mitigation percentage for runoff volumes and sediment losses under no-till compared with conventional tillage, assuming that NT provides less runoff and soil loss than CT at that specific event. However, this may not necessarily happen in all cases. When no-till provided no mitigation, i.e. runoff volume or sediment loss was higher in NT than in CT, the calculations need to be adjusted to correctly estimate the lack of mitigation (and so the increase) in runoff and sediment loss, as reported in Eqs. (2) and (4).

The rainfall conditions, runoff water samplings, and crops cultivated in the NT and CT fields during the experimental periods are illustrated in Fig. 3.

Runoff, sediment loss, and sediment concentration data were analysed using the TIBCO Statistica 13 software for Windows (TIBCO Software Inc., Palo Alto, CA, USA). Prior to statistical comparisons, data normality was tested using a Shapiro–Wilk test ($p < 0.05$). For each runoff event, a Student's *t*-test ($\alpha = 0.05$) was used to determine significant differences between CT and NT in terms of runoff volume, sediment loss, and sediment concentration.

3. Results and discussion

3.1. Soil properties

The soils at both sites were determined to be Fluvi-Calcaric Cambisol (FAO-UNESCO, 1990), classified as silty-loam. The NT soil comprised 19.5% sand, 60.8% silt, and 19.7% clay, and the CT soil comprised 25.1% sand, 57.1% silt, and 17.8% clay. The pH was 7.85 and 7.38 for the NT and CT soil, respectively.

Table 1 summarises the results of the tests conducted on undisturbed soil samples. When the soil was sampled, the lowest *BD* and the highest K_s and θ_s values were recorded in the CT soil. Tillage should decrease the degree of soil compaction and increase its porosity, yielding an increase in hydraulic conductivity, which is what was observed. According to Fraser et al. (2010), tillage can also affect soil bulk density. The track position in the non-tilled soil showed K_S, θ_S, and *BD* values lower than those measured in the no-track position. It should be noted that samples were collected more than one year after the last tillage of the CT field. Therefore, we can assume that sampling sooner after tillage might show more marked differences in soil hydrological properties between CT and NT soil.

3.2. Runoff volumes

During the monitoring period, 24 runoff events (RE1 to RE24) occurred (Fig. 3). A total rainfall of 640 mm was recorded across both sampling periods, with very high seasonal and interannual variations (Table 2). From May to October 2017, 263 mm of rainfall was recorded, with 146 mm concentrated in September. From May to September 2018, 377 mm of rainfall was recorded, distributed throughout the

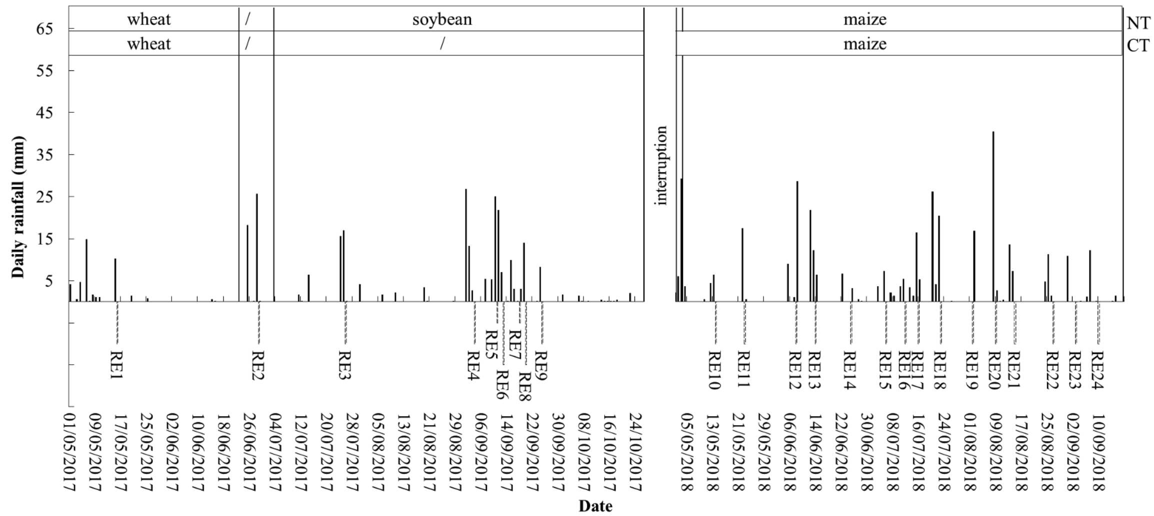

Fig. 3. Daily rainfall monitored from May to October 2017 and from May to September 2018. Dotted lines indicate the sampling of runoff water. The crops in NT and CT plot are indicated at the top.

whole period.

Fig. 4 reports runoff volumes measured for each runoff event in the NT and CT plots. Measurement variability was higher in the tilled than no-tilled plots. The runoff amount in the CT plot ranged from 0.08 mm (RE14) to 8.67 mm (RE18), and in the NT plot from 0.07 mm (RE9) to 3.25 mm (RE20). For runoff events RE9 and RE20, in two out of three CT sub-plots, runoff exceeded the maximum measurable volume of the collection tank. Therefore, the actual runoff in this event may have been higher. The runoff coefficient values ranged from 0.84% (RE14) to 28.16% (RE1) in the CT plot, and from 0.88 (RE5) to 11.19% (RE17) in the NT plot.

Higher runoff volumes were generally measured in the CT plot, although the difference was only statistically significant in 8 of the 24 runoff events (RE3, RE4, RE5, RE6, RE13, RE15, RE18, and RE20). Runoff volume was higher in the NT than CT plot in only 4 of the 24 runoff events (RE10, RE11, RE14, and RE24). However, the difference between runoff in the NT and CT plots was only significant in RE10; this was the first runoff event of the second sampling period, and it should be noted that, three weeks before this event, the CT field was harrowed. The differences in CT and NT runoff volumes observed during this event can be explained by the higher infiltration rate and surface storage of the CT soil due to its increased surface roughness in the weeks after tillage; this surface roughness immediately after tillage operations assisted in rainfall catchment and infiltration. The effect of tillage on soil morphology is time-variant and tends to decrease with time. A similar effect was observed by Gomez et al. (2009) and Romero et al. (2007) in olive orchards, and by Myers and Wagger (1996) in conventional tillage maize. In particular, Myers and Wagger (1996) observed that, just after the seedbed preparation, the soil surface was rougher and cloddy compared to a non-tilled soil, favouring rainfall infiltration. However, this condition was not permanent. As intense rainfall events occurred, surface sealing and crusting initiated, with negative consequences for runoff. This study was conducted on a different type of soil, with a sandy clay loam texture and with a particular tendency to sealing and crust formation, which may have exacerbated the observed changes in soil surface throughout the season. However, a similar phenomenon was also observed by Tarolli et al. (2019) on the same CT and NT fields as in our research. This work analysed the surface morphology of three 4 m^2 plots per field using the Structure from Motion photogrammetric technique. This technique provides a mathematical interpretation of a sequence of images taken with precise technical rules to construct a three-dimensional representation of an object (the soil in this case), and it is a valuable tool to understand the physical processes that underlie runoff and soil erosion and to plan sustainable interventions (Tarolli and Straffelini, 2020).

The survey was carried out on both fields 26 days after the seedbed preparation of the CT field, which had been ploughed a few months earlier. The high-resolution Digital Elevation Models (2 cm grid cell size) processed for the plots revealed that after less than one month, the surface of CT soil, rougher just after seedbed preparation, was smoother than NT. Because of this smoothing, the CT soil presented less pronounced surface concavities and convexities than the NT soil. As a consequence, the authors found higher potential water depth in NT (from 3.4 to 4.1 cm) than in CT soil (from 0.7 to 1.5 cm). That means that, under the same wetness and rainfall conditions, more water can be stored for longer in the surface concavities of a non-tilled soil, allowing more time for infiltration and reducing surface runoff. The generation of runoff is therefore strongly affected by the surface micro-topographical structures dictating how water exceeds the storage capacity of soil surface depressions, therefore spilling out and moving through the network of depressions (Antoine et al., 2009; Appels et al., 2011; Frei and Fleckenstein, 2014).

Runoff coefficients in the CT plot increased markedly after the first high-intensity rainfall (RE12), which may have initiated surface sealing and crusting and promoted roughness loss. Runoff coefficients in the CT plot then remained high until the last event, except for RE14 and RE16

Table 1
Mean values (± standard error) of saturated hydraulic conductivity (K_S), saturated soil water content (θ_S), and oven-dry soil bulk density (*BD*) measured in the NT and CT plots.

Field	Sample	K_S (cm min^{-1})	θ_S (cm^3 cm^{-3})	*BD* (g cm^{-3})
CT	–	$3.34 \cdot 10^{-2}$ (± $5.525 \cdot 10^{-3}$) *a*	0.483 (± 0.0245) *a*	1.547 (± 0.0477) *a*
NT	track	$9.24 \cdot 10^{-4}$ (± $7.231 \cdot 10^{-4}$) *a*	0.419 (± 0.0078) *a*	1.663 (± 0.0389) *ab*
NT	no-track	$1.46 \cdot 10^{-3}$ (± $7.495 \cdot 10^{-4}$) *a*	0.448 (± 0.0096) *a*	1.737 (± 0.0397) *b*

Values in columns differ significantly when labelled with different letters (Tukey post hoc test with $p < 0.05$; n = 3).

Table 2
Rainfall characteristics of the events generating runoff volumes.

Runoff event	Sampling date	Rainfall amount (mm)	Rainfall duration (hours)	Maximum rainfall intensity in 5 min (mm hour^{-1})	Maximum rainfall intensity in 10 min (mm hour^{-1})	Maximum rainfall intensity in 30 min (mm hour^{-1})	Maximum rainfall intensity in 60 min (mm hour^{-1})	Mean rainfall intensity (mm hour^{-1})	Cumulative precipitation during the previous 7 days (mm)	Cumulative precipitation during the previous 15 days (mm)	Cumulative precipitation during the previous 30 days (mm)	Cumulative precipitation during the previous 45 days (mm)
RE1	16/5/2017	10.2	14.33	16.8	13.2	8.0	5.4	0.71	11.2	34.0	74.0	94.0
RE2	29/6/2017	25.6	7.08	33.6	26.4	21.2	11.6	3.61	44.2	44.2	45.0	47.2
RE3	26/7/2017	32.6	33.17	86.4	62.4	32.8	16.4	0.98	32.8	39.4	67.0	86.0
RE4	4/9/2017	42.6	47.25	112.8	100.8	43.2	21.6	0.90	42.6	42.8	50.2	87.2
RE5	11/9/2017	30.2	23.17	12.0	9.6	7.2	5.6	1.30	57.4	100.2	103.8	111.8
RE6	13/9/2017	28.6	19.58	52.8	50.4	33.6	20.6	1.46	64.4	107.0	110.8	114.6
RE7	18/9/2017	12.8	29.33	12.0	9.6	9.6	6.4	0.44	23.2	80.6	123.6	130.8
RE8	20/9/2017	17.0	28.08	7.2	6.0	5.6	5.0	0.61	30.2	94.6	137.4	143.2
RE9	25/9/2017	8.2	10.08	14.4	14.4	6.4	4.2	0.81	22.4	67.4	145.8	149.4
RE10	14/5/2018	10.8	29.08	28.8	22.8	8.0	4.4	0.37	11.4	52.4	52.4	90.8
RE11	23/5/2018	17.4	20.00	12.0	9.6	8.4	7.0	0.87	18.0	29.4	70.4	82.6
RE12	8/6/2018	29.6	15.92	62.4	61.2	42.4	23.4	1.86	38.6	38.6	68.0	109.0
RE13	14/6/2018	40.4	38.58	50.4	49.2	20.0	10.0	1.05	69.0	79.0	97.0	149.4
RE14	25/6/2018	9.8	77.67	12.0	8.4	4.0	2.6	0.13	9.8	50.2	88.8	117.6
RE15	6/7/2018	7.2	9.08	55.2	36.0	12.8	6.4	0.79	10.8	21.4	91.4	101.0
RE16	12/7/2018	9.0	36.67	33.6	19.2	6.8	3.4	0.25	12.6	23.6	52.6	113.0
RE17	16/7/2018	22.2	32.00	100.8	67.2	24.0	12.2	0.69	35.4	49.8	60.4	139.4
RE18	23/7/2018	50.8	58.75	52.8	48.0	43.6	25.8	0.86	50.8	86.2	104.6	151.6
RE19	2/8/2018	16.6	1.50	43.2	38.4	32.8	16.6	11.07	16.8	67.8	114.0	128.2
RE20	9/8/2018	40.4	1.58	84.0	78.0	74.0	40.4	25.52	43.0	60.0	142.6	161.4
RE21	15/8/2018	20.8	29.08	50.4	48.0	25.6	12.8	0.72	24.0	81.2	132.2	182.0
RE22	27/8/2018	12.6	25.50	16.8	15.6	10.4	5.6	0.49	17.4	38.2	98.6	172.6
RE23	3/9/2018	No data[a]							10.8	28.2	92.6	134.2
RE24	10/9/2018	13.4	10.92	12.0	12.0	8.4	6.0	1.23	13.8	24.6	62.8	123.2

[a] On 3/9/2018, no precipitation data could be retrieved due to rain-gauge malfunctioning.

when rainfall intensity was very low. As highlighted by Myers and Wagger (1996), surface sealing and crust formation appear to play an important role in surface runoff.

Cumulated runoff was lower in the first than in the second sampling period, for both the NT plot (5.6 and 20.1 in the first and second period, respectively) and CT plot (18.8 mm and 42.1 in the first and second period, respectively). However, the observed differences can partly be explained by the higher total rainfall amount registered in the second period, and by the occurrence of some brief and very intense rainfall events during the summer. Considering the entire study period, the cumulated runoff was higher in the CT than the NT plot (60.9 and 25.7 mm, respectively). Overall, NT practices yielded an average reduction of about 58% in runoff volumes compared with the tilled plot. Similar results, showing a substantial reduction of runoff in conservation agriculture compared with conventional tillage schemes, have been obtained in other geographical areas and different croplands, such as wheat and teff in Ethiopia (Araya et al., 2011), wheat/lupine rotation in Australia (Zhang et al., 2007), a 4-yr corn/wheat/meadow/meadow rotation in Ohio, USA (Shipitalo and Edwards, 1998), and a corn planting simulation in Kentucky, USA (Seta et al., 1993).

3.3. Sediment losses and concentrations

Larger sediment losses were generally measured in the CT than in

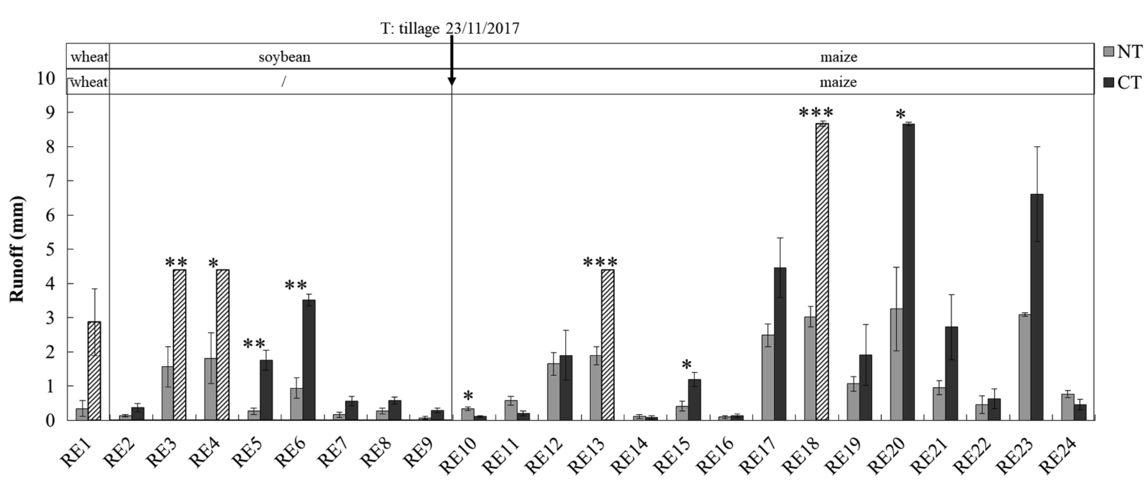

Fig. 4. Runoff volumes (expressed in mm) sampled from NT and CT plots at each runoff event. Vertical bars indicate standard error; the crops in CT and NT fields and the date of the tillage operation performed on CT field are indicated at the top. The dotted columns represent the events in which runoff volumes exceeded the capacity of the tanks for one or more CT sub-plots, so the runoff volume could not be precisely quantified. Asterisks indicate statistical significance levels: *** = $p < 0.001$; ** = $p < 0.01$; * = $p < 0.05$.

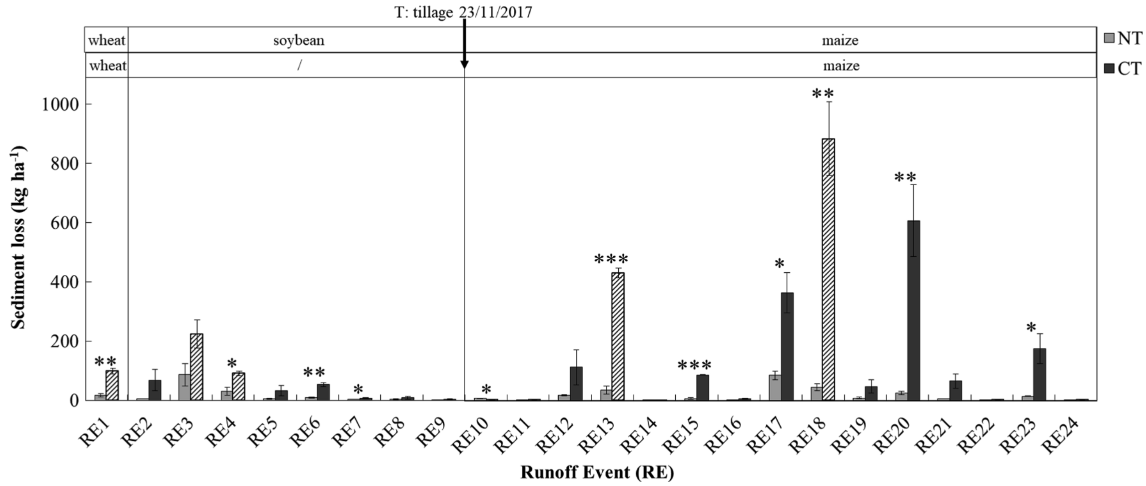

Fig. 5. Sediment loss from NT and CT plots at each runoff event. Vertical bars indicate standard error; the crops in CT and NT fields and the date of tillage operation performed on CT field are indicated at the top. The dotted columns represent the events in which runoff volumes exceeded the capacity of the tanks for one or more CT sub-plot, so the sediment loss could not be precisely quantified. Asterisks indicate statistical significance levels: *** = $p < 0.001$; ** = $p < 0.01$; * = $p < 0.05$.

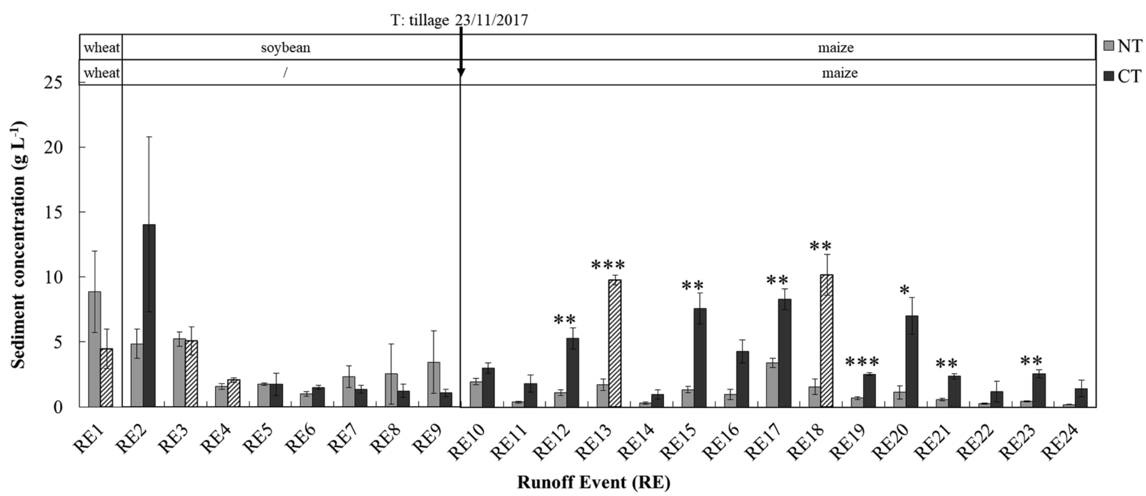

Fig. 6. Sediment concentration from NT and CT plots at each runoff event. Vertical bars indicate standard error; the crops in CT and NT fields and the date of tillage operation performed on CT field are indicated at the top. The dotted columns represent the events in which runoff volumes exceeded the capacity of the tanks for one or more CT sub-plot, so the sediment concentration could not be precisely quantified. Asterisks indicate statistical significance levels: *** = $p < 0.001$; ** = $p < 0.01$; * = $p < 0.05$.

the NT plot, although the difference was statistically significant in only 10 of the 24 runoff events (RE1, RE4, RE6, RE7, RE10, RE13, RE15, RE17, RE18, RE20, and RE23). Sediment losses measured in the NT and CT plots at each runoff event are reported in Fig. 5. The sediment loss in the CT plot ranged from 0.63 kg ha^{-1} $event^{-1}$ (RE14) to 884 kg ha^{-1} $event^{-1}$ (RE18), whereas in the NT plot from 0.29 kg ha^{-1} $event^{-1}$ (RE14) to 86 kg ha^{-1} $event^{-1}$ (RE3). Measurement variability was higher in the CT than in the NT plot. Sediment loss was higher in the NT than in the CT plot only in RE10, but this was due to the higher runoff volume measured in the NT plot during this event and not to the sediment concentration, which was lower in the NT than the CT plot (sediment concentrations are reported in Fig. 6). The cumulative sediment loss was higher in CT (3368 kg ha^{-1}) than in NT (406 kg ha^{-1}). Higher total sediment losses were measured in the second (2782 and 247 kg ha^{-1} $event^{-1}$ for CT and NT, respectively) compared with the first (586 and 159 kg ha^{-1} $event^{-1}$ for CT and NT, respectively) sampling period. Overall, NT practices coincided with a 50% to 95% reduction in sediment losses. In other geographical areas, TerAvest et al. (2015), Araya et al. (2011), Tiessen et al. (2010), and Schuller et al. (2007) (in Malawi, Ethiopia, Canada, and Chile, respectively) reported similar values of sediment loss reduction under a conservation tillage regime, despite the fact that the NT soil sampled in our study was an immature conservation soil still within a transition period.

Sediment concentration also appears to have been affected by soil management. The concentration in runoff was lower in the NT than CT treatment for the majority of runoff events, although the difference was only statistically significant for nine (RE12, RE13, RE15, RE17, RE18, RE19, RE20, RE21, and RE23) (Fig. 6). The sediment concentration was higher in NT than CT for only five events in the first sampling period (RE1, RE3, RE7, RE8, and RE9), but none of these showed a statistically significant difference. The average sediment concentration in NT was only 47% of CT. Indeed, reductions in runoff rate and volume have been shown to decrease the capacity of surface runoff to carry sediment (Araya et al., 2011; Myers and Wagger, 1996; Tarolli et al., 2019; Vaezi et al., 2017). What is also interesting is that the average sediment concentration from NT in the second sampling period (1.05 g L^{-1}) was lower than that recorded in the first (3.51 g L^{-1}), whereas for CT there were no differences between the two periods. These lower concentrations may have resulted from the ongoing consolidation of the undisturbed soil surface during the period of our research, leading to a

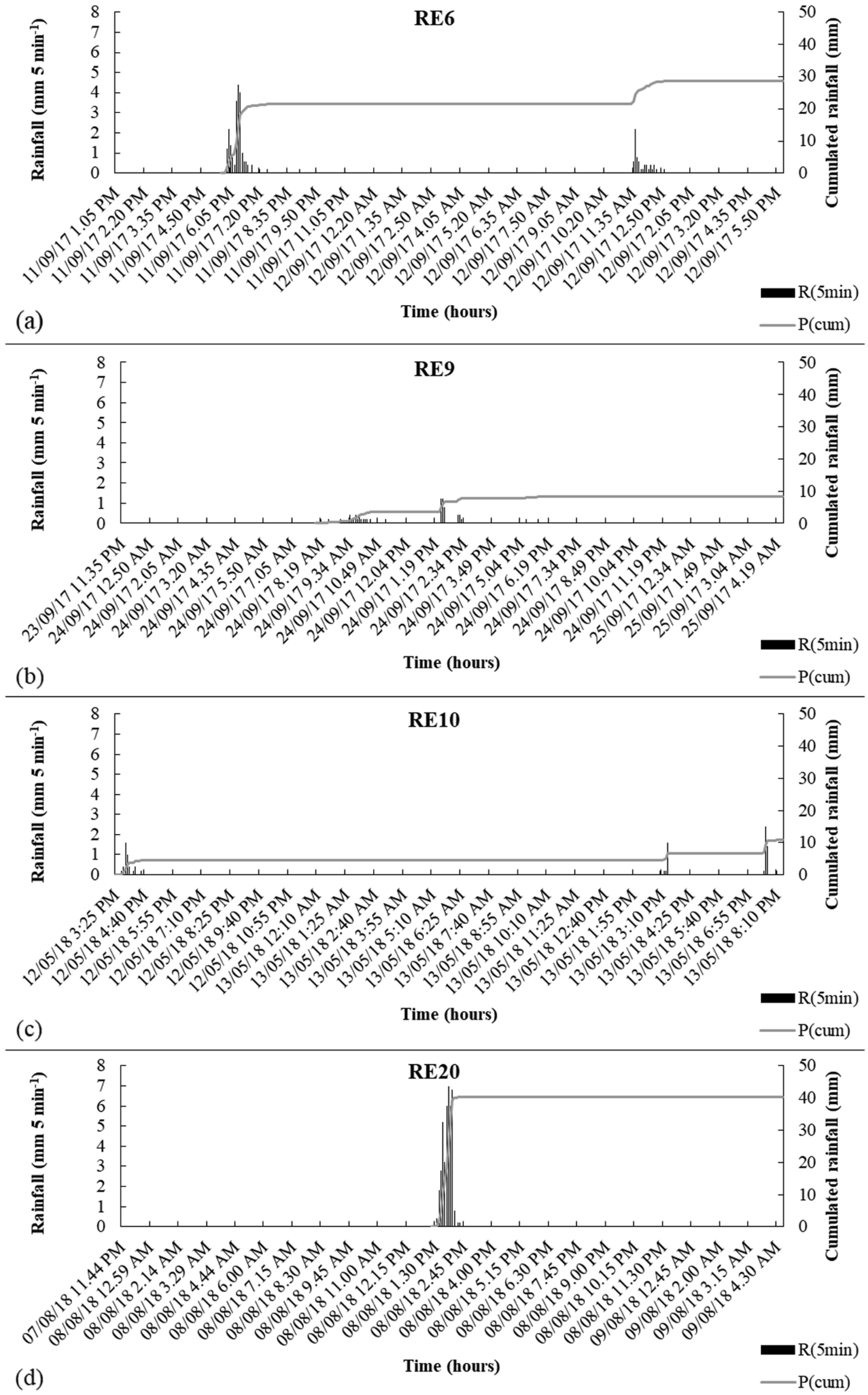

Fig. 7. Examples of rainfall events causing runoff with pluviometer data (5 min step). R(5 min) = rain intensity at 5 min step; P(cum) = cumulative rainfall.

lower sediment detachment during rainfall events.

Four cases of runoff deriving from rainfall events are shown in Fig. 7, two in 2017 and two in 2018. Fig. 7a represents a late summer rainfall on 13/9/2017 (rainfall, 28.6 mm; maximum 5-min intensity, 52.8 mm h^{-1}), which caused considerable runoff volumes from both the CT and NT plots. Measured runoff coefficients and sediment yields were 12.3% and 52.9 kg ha^{-1} $event^{-1}$ in the CT plot and 3.3% and 9.0 kg ha^{-1} $event^{-1}$ in the NT plot. Fig. 7b shows a rainfall event on 25/9/2017 for which light runoff was measured (rainfall, 8.2 mm; maximum 5-min intensity, 14.4 mm h^{-1}), which caused little soil erosion. However, this event was preceded by several others in the previous 30 days, giving a cumulative precipitation of 146 mm. These previous events would have increased the soil water content, with the final event then causing soil surface saturation and generating a light saturation-excess runoff in both CT and NT. The runoff coefficients and sediment yields were 3.5% and 3.5 kg ha^{-1} $event^{-1}$ in the CT plot and 0.9% and 1.0 kg ha^{-1} $event^{-1}$ in the NT plot. Fig. 7c shows a summer rainfall event on 14/5/2018 (rainfall, 10.8 mm; maximum 5-min intensity, 28.8 mm h^{-1}), three weeks after harrowing the CT field. Low runoff was measured in both plots but, as mentioned in Section 3.2, runoff was higher in NT than in CT. The runoff coefficients and sediment yields were 1.0% and 3.1 kg ha^{-1} event^{-1} in the CT plot and 3.1% and 6.3 kg ha^{-1} event^{-1} in the NT plot. The observed values were attributed to the effect of tillage operations on CT soil morphology and conductivity, which is assumed to increase after tillage (Biddoccu et al., 2017, 2016). Erosion was detected in both plots, but in NT was twice that in CT. Fig. 7d represents a summer storm on 9/8/2018, which accounted for 40.4 mm of rainfall in a very short time (one hour), with a maximum 5-min intensity of 84.0 mm h^{-1}. This event occurred 15 weeks after tillage of the CT soil. It is likely that this short and intense rainfall increased the soil water content very rapidly in both soils. However, as the CT soil had a lower infiltration rate and surface storage capacity, it may have reached soil saturation earlier than in NT. Thus, a higher runoff caused by infiltration excess occurred in CT (8.67 mm) than in NT (3.25 mm). Sediment yield was very high in the CT plot (606.4 kg ha^{-1} event^{-1}) and low in NT (24.4 kg ha^{-1} event^{-1}). As mentioned by Peña-Angulo et al. (2019), increased frequency of short and intense rainfall event can have a significant impact on the hydrological and erosion response and the export of sediment, and this impact could be much higher under conventional than conservation agriculture.

3.4. Evaluation of no-till practice on runoff and sediment loss reduction

The *RRB* and *SRB* values reported in Fig. 8 confirm a reduction in runoff and sediment loss in the NT compared with the CT plot for most runoff events. As mentioned above, the different treatments (tillage and no-till) produced a different surface morphology in the two soils. The NT soil, having not been subjected to tillage for four years, was unaffected by mechanical disturbance factors and its surface morphology was consolidated over time, improving its surface concavities and water storage capacity, and consequently its ability to attenuate both runoff and soil erosion. As mentioned in the Section 3.2, Tarolli et al. (2019) found that the potential water depth in NT was roughly three times that in CT due to the more pronounced concavities and convexities on the NT surface. These high storage capacity concavities retained rainfall water and runoff flow, thus delaying runoff. Rainfall was therefore more likely to infiltrate the soil and produce less runoff. Conversely, on the CT soil, tillage initially induced a rougher surface after seedbed preparation, but the surface became smoother over time and more subject to crust formation. As the season advanced, the CT soil developed a reduced ability for infiltration and resistance to detachment, resulting in the potential for greater yields of runoff and sediment. In NT, micro-depressions can readily intercept and trap sediments, which greatly affects the influence of sediment output; this highlights the importance of a rougher surface. These observations are also supported by Potter et al. (1995), Bewket and Sterk (2003), Barbosa et al. (2009), and Wang et al. (2017).

The lack of soil disturbance is an essential factor that contributes to reducing the runoff and soil erosion from a non-tilled field, but it is not the only one. In the complex framework of conservation agriculture practices, also the crop residues have to be considered. As pointed out by Saco et al. (2020), surface runoff and vegetation cover are deeply connected with topography, slopes, and flow paths, and they

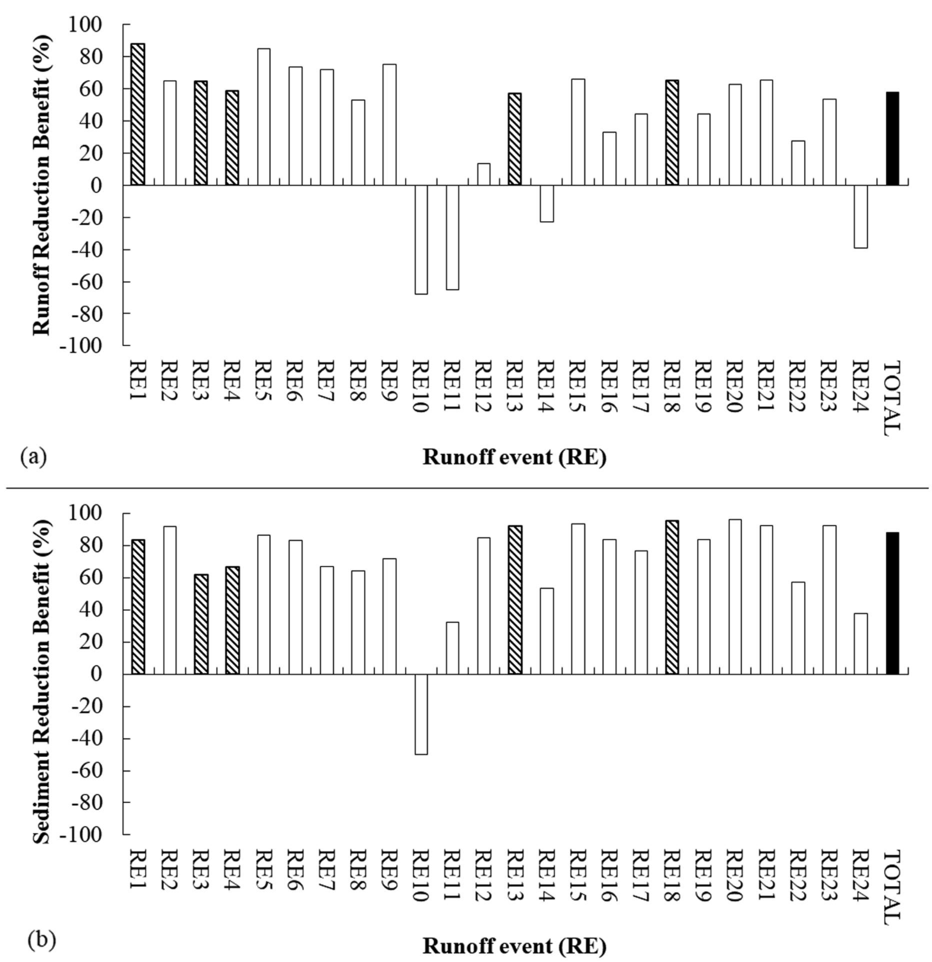

Fig. 8. Runoff Reduction Benefit (*RRB*) (a) and Sediment Reduction Benefit (*SRB*) (b) at each runoff event (white columns) and for the entire sampling period (black columns). The dotted columns represent the events in which runoff volumes exceeded the capacity of the tanks for one or more CT sub-plot.

continuously change influencing each other. The role of crop residues played as a protective cover in no-till systems has been widely recognized in the literature (Blanco-Canqui and Lal, 2009; Cerdà et al., 2016; Kurothe et al., 2014; Leys et al., 2010; Lindstrom, 1986; Mostaghimi et al., 1988). From a physical point of view, crop residues preserve the soil from erosion by protecting the soil below the residues from the direct raindrop impact, and increase soil roughness, delaying runoff generation and reducing runoff velocity (Afyuni et al., 1997; Jordán et al., 2010; Keesstra et al., 2019). From a chemical point of view, an increase in infiltration and resistance to detachment can also be given by the release of organic compounds during the decomposition of crop residues, which can bind soil particles, improving aggregate structural stability of the soil and preventing the collapse of macropores (Blanco-Canqui, 2011; Mhazo et al., 2016; Rhoton et al., 2002). *SRB* was greater than the *RRB* over the entire study period. This indicated that the no-till regime showed a better control of sediment loss than it did the runoff amount. Several studies have suggested that conservation cropping systems appear to be more efficient in decreasing soil loss than runoff at a plot scale (Armand et al., 2009; Leys et al., 2010; Maetens et al., 2012; Montgomery, 2007; Wang et al., 2017). As mentioned above, soon after seedbed preparation, a tilled soil is characterised by micro-depressions or furrows that can store water and sediment during a rainfall event. However, this artificially created surface morphology is not as stable as it can be in non-tilled soil, and it is soon smoothed out by the action of rainfall. During rainfall events, eroded sediment is transported with runoff and it accumulates in surface depressions or furrows. This results in the smoothing of the soil surface, as these concavities are filled with sediment, and in less space at a later stage for retention of sediment. This is not the case in NT soil, because surface morphology and soil aggregates are assumed to be more stable and consolidated over time when the soil is not tilled for several years (Paul et al., 2013). Thus, for NT, the benefits for sediment reduction were greater than those for runoff. During the first sampling period, *RRB* was always greater than 50% whereas, during the second period, 4 out of 15 runoff events showed a negative value of *RRB*, and overall the *RRB* was lower. This behaviour was not observed for *SRB* values, which were similar in the first and second sampling period except for RE10, which was an isolated case. The variability in runoff ratio and soil loss ratio between different years was described by Maetens et al. (2012), who explored the effectiveness of soil and water conservation techniques (including no-till) on runoff and soil erosion in Europe and the Mediterranean, analysing 65 time-series of annual runoff and sediment loss. The authors showed that the runoff ratio, calculated as the annual runoff ratio between no-till and conventional tillage plots, tended to increase over a six-year period following first application of the no-till technique, suggesting that the effectiveness of no-till in reducing runoff decreases over time. Since we studied the third and fourth years of no-till in our research, it appears likely that a slight and gradual decrease in runoff reduction effectiveness in NT is beginning, and further monitoring could confirm this hypothesis. Similarly to what we observed, Maetens et al. (2012) did not identify such a trend for sediment loss ratio, attributing this to increased surface sealing when the soil is not tilled for several years.

4. Conclusion

In this study, we investigated the effects of no-till on runoff and soil erosion under natural rainfall conditions in field plots. Higher runoff volumes and sediment losses were generally measured in the CT than in NT plot. Only the runoff event occurred just after the CT soil harrowing produced a significantly lower runoff and sediment loss in CT than in NT field, evidencing the effect of soil tillage on rainfall infiltration and sediment detachment. After four years of using NT practices, reductions of over 50% in runoff volumes and 50% to 95% in sediment losses were achieved. Although the studied field was still in the transition period, NT was beneficial in reducing runoff and soil erosion, in turn promoting rainfall water and soil conservation. The *RRB* and *SRB* values confirm a reduction in runoff and sediment loss in the NT compared with the CT plot, but the no-till regime showed a better control of sediment loss than it did the runoff amount as indicated by the *SRB* greater than the *RRB* over the entire study period.

In a tilled field, surface morphology and soil hydrological properties are subjected to considerable variations over time, due to tillage operations and field management. For this reason, further and frequent monitoring of hydrological properties and soil morphology, with the use of remote sensing techniques and digital terrain analysis, are required to provide a more solid basis from which to draw conclusions. This could provide useful information and shed some more light when modelling water fluxes and identifying their hydrological connectivity as well as characterising the pesticide transport in tilled and non-tilled soils.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

Afyuni, M.M., Wagger, M.G., Leidy, R.B., 1997. Runoff of two sulfonylurea herbicides in relation to tillage system and rainfall intensity. J. Environ. Qual. 26, 1318–1326. https://doi.org/10.2134/jeq1997.00472425002600050018x.

Antoine, M., Javaux, M., Bielders, C., 2009. What indicators can capture runoff-relevant connectivity properties of the micro-topography at the plot scale? Adv. Water Resour. 32, 1297–1310. https://doi.org/10.1016/j.advwatres.2009.05.006.

Appels, W.M., Bogaart, P.W., van der Zee, S.E.A.T.M., 2011. Influence of spatial variations of microtopography and infiltration on surface runoff and field scale hydrological connectivity. Adv. Water Resour. 34, 303–313. https://doi.org/10.1016/j.advwatres.2010.12.003.

Araya, T., Cornelis, W.M., Nyssen, J., Govaerts, B., Bauer, H., Gebreegziabher, T., Oicha, T., Raes, D., Sayre, K.D., Haile, M., Deckers, J., 2011. Effects of conservation agriculture on runoff, soil loss and crop yield under rainfed conditions in Tigray, Northern Ethiopia. Soil Use Manage. 27, 404–414. https://doi.org/10.1111/j.1475-2743.2011.00347.x.

Armand, R., Bockstaller, C., Auzet, A., Vandijk, P., 2009. Runoff generation related to intra-field soil surface characteristics variability. Application to conservation tillage context. Soil Tillage Res. 102, 27–37. https://doi.org/10.1016/j.still.2008.07.009.

Armengot, L., Berner, A., Blanco-Moreno, J.M., Mäder, P., Sans, F.X., 2015. Long-term feasibility of reduced tillage in organic farming. Agron. Sustain. Dev. 35, 339–346. https://doi.org/10.1007/s13593-014-0249-y.

Barbosa, F.T., Bertol, I., Luciano, R.V., Gonzalez, A.P., 2009. Phosphorus losses in water and sediments in runoff of the water erosion in oat and vetch crops seed in contour and downhill. Soil Tillage Res. 106, 22–28. https://doi.org/10.1016/j.still.2009.09.004.

Basch, G., González-Sánchez, E.J., Gómez McPherson, H., Kassam, A., 2011. Opportunities for conservation agriculture in the EU Common Agricultural Policy 2014-2020. Proc. 5th World Congr. Conserv. Agric. Inc. 3rd Farming Syst. Des. Conf. Brisbane, Aust.

Berger, A., Friedrich, T., Kienzle, J., 2010. Soils, plant growth and crop production. Conserv. Agric. 1, 108–112.

Bewket, W., Sterk, G., 2003. Assessment of soil erosion in cultivated fields using a survey methodology for rills in the Chemoga watershed. Ethiopia. Agric. Ecosyst. Environ. 97, 81–93. https://doi.org/10.1016/S0167-8809(03)00127-0.

Biddoccu, M., Ferraris, S., Opsi, F., Cavallo, E., 2016. Long-term monitoring of soil management effects on runoff and soil erosion in sloping vineyards in Alto Monferrato (North-West Italy). Soil Tillage Res. 155, 176–189. https://doi.org/10.1016/j.still.2015.07.005.

Biddoccu, M., Ferraris, S., Pitacco, A., Cavallo, E., 2017. Temporal variability of soil management effects on soil hydrological properties, runoff and erosion at the field scale in a hillslope vineyard. North-West Italy. Soil Tillage Res. 165, 46–58. https://doi.org/10.1016/j.still.2016.07.017.

Blanco-Canqui, H., 2011. Does no-till farming induce water repellency to soils? Soil Use Manage. 27, 2–9. https://doi.org/10.1111/j.1475-2743.2010.00318.x.

Blanco-Canqui, H., Lal, R., 2009. Crop residue removal impacts on soil productivity and environmental quality. CRC. Crit. Rev. Plant Sci. 28, 139–163. https://doi.org/10.

1080/07352680902776507.
Bogunovic, I., Pereira, P., Kisic, I., Sajko, K., Sraka, M., 2018. Tillage management impacts on soil compaction, erosion and crop yield in Stagnosols (Croatia). Catena 160, 376–384. https://doi.org/10.1016/j.catena.2017.10.009.
Bouma, J., McBratney, A., 2013. Framing soils as an actor when dealing with wicked environmental problems. Geoderma 200–201, 130–139. https://doi.org/10.1016/j.geoderma.2013.02.011.
Cerdà, A., González-Pelayo, Ó., Giménez-Morera, A., Jordán, A., Pereira, P., Novara, A., Brevik, E.C., Prosdocimi, M., Mahmoodabadi, M., Keesstra, S., Orenes, F.G., Ritsema, C.J., 2016. Use of barley straw residues to avoid high erosion and runoff rates on persimmon plantations in Eastern Spain under low frequency-high magnitude simulated rainfall events. Soil Res. 54, 154–165. https://doi.org/10.1071/SR15092.
Cessna, A.J., McConkey, B.G., Elliott, J.A., 2013. Herbicide transport in surface runoff from conventional and zero-tillage fields. J. Environ. Qual. 42, 782. https://doi.org/10.2134/jeq2012.0304.
FAO-UNESCO, 1990. Soil Map of the World. Revised Legend.
Fraser, P.M., Curtin, D., Beare, M.H., Meenken, E.D., Gillespie, R.N., 2010. Temporal changes in soil surface elevation under different tillage systems. Soil Sci. Soc. Am. J. 74, 1743. https://doi.org/10.2136/sssaj2009.0251.
Frei, S., Fleckenstein, J.H., 2014. Representing effects of micro-topography on runoff generation and sub-surface flow patterns by using superficial rill/depression storage height variations. Environ. Model. Softw. 52, 5–18. https://doi.org/10.1016/j.envsoft.2013.10.007.
Gee, G.W., Or, D., 2002. 2.4 Particle-size analysis, in: Methods of Soil Analysis: Part 4 Physical Methods, 5. pp. 255–293.
Gomez, J., Sobrinho, T., Giràldez, J., Fereres, E., 2009. Soil management effects on runoff, erosion and soil properties in an olive grove of Southern Spain. Soil Tillage Res. 102, 5–13. https://doi.org/10.1016/j.still.2008.05.005.
Hobbs, P.R., Sayre, K., Gupta, R., 2008. The role of conservation agriculture in sustainable agriculture. Philos. Trans. R. Soc. B Biol. Sci. 363, 543–555. https://doi.org/10.1098/rstb.2007.2169.
Hossain, M.M., 2013. The apotheosis of conservation agriculture - A review. J. Bangladesh Agric. Univ. 11, 241–248.
Jia, L., Zhao, W., Zhai, R., Liu, Y., Kang, M., Zhang, X., 2019. Regional differences in the soil and water conservation efficiency of conservation tillage in China. Catena 175, 18–26. https://doi.org/10.1016/j.catena.2018.12.012.
Jordán, A., Zavala, L.M., Gil, J., 2010. Effects of mulching on soil physical properties and runoff under semi-arid conditions in southern Spain. Catena 81, 77–85. https://doi.org/10.1016/j.catena.2010.01.007.
Keesstra, S.D., Rodrigo-Comino, J., Novara, A., Giménez-Morera, A., Pulido, M., Di Prima, S., Cerdà, A., 2019. Straw mulch as a sustainable solution to decrease runoff and erosion in glyphosate-treated clementine plantations in Eastern Spain. An assessment using rainfall simulation experiments. Catena 174, 95–103. https://doi.org/10.1016/j.catena.2018.11.007.
Knowler, D., Bradshaw, B., 2007. Farmers' adoption of conservation agriculture: A review and synthesis of recent research. Food Policy 32, 25–48. https://doi.org/10.1016/j.foodpol.2006.01.003.
Kurothe, R.S., Kumar, G., Singh, R., Singh, H.B., Tiwari, S.P., Vishwakarma, A.K., Sena, D.R., Pande, V.C., 2014. Effect of tillage and cropping systems on runoff, soil loss and crop yields under semiarid rainfed agriculture in India. Soil Tillage Res. 140, 126–134. https://doi.org/10.1016/j.still.2014.03.005.
Leys, A., Govers, G., Gillijns, K., Berckmoes, E., Takken, I., 2010. Scale effects on runoff and erosion losses from arable land under conservation and conventional tillage: The role of residue cover. J. Hydrol. 390, 143–154. https://doi.org/10.1016/j.jhydrol.2010.06.034.
Lindstrom, M.J., 1986. Effects of residue harvesting on water runoff, soil erosion and nutrient loss. Agric. Ecosyst. Environ. 16, 103–112. https://doi.org/10.1016/0167-8809(86)90097-6.
Maetens, W., Poesen, J., Vanmaercke, M., 2012. How effective are soil conservation techniques in reducing plot runoff and soil loss in Europe and the Mediterranean? Earth Sci. Rev. 115, 21–36. https://doi.org/10.1016/j.earscirev.2012.08.003.
Mhazo, N., Chivenge, P., Chaplot, V., 2016. Tillage impact on soil erosion by water: Discrepancies due to climate and soil characteristics. Agric. Ecosyst. Environ. 230, 231–241. https://doi.org/10.1016/j.agee.2016.04.033.
Montgomery, D.R., 2007. Soil erosion and agricultural sustainability. Proc. Natl. Acad. Sci. 104, 13268–13272. https://doi.org/10.1073/pnas.0611508104.
Mostaghimi, S., Dillaha, T.A., Shanholtz, V.O., Member, A., Asae, A.M., S. Mostaghimi, S., T. A. Dillaha, T.A., V. O. Shanholtz, V.O., 1988. Influence of Tillage Systems and Residue Levels on Runoff, Sediment, and Phosphorus Losses. Trans. ASAE 31, 0128–0132. doi:10.13031/2013.30677.
Myers, J.L., Wagger, M.G., 1996. Runoff and sediment loss from three tillage systems under simulated rainfall. Soil Tillage Res. 39, 115–129.
Nyssen, J., Poesen, J., Moeyersons, J., Haile, M., Deckers, J., 2008. Dynamics of soil erosion rates and controlling factors in the Northern Ethiopian Highlands – towards a sediment budget. Earth Surf. Process. Landforms 33, 695–711. https://doi.org/10.1002/esp.1569.
Paul, B.K., Vanlauwe, B., Ayuke, F., Gassner, A., Hoogmoed, M., Hurisso, T.T., Koala, S., Lelei, D., Ndabamenye, T., Six, J., Pulleman, M.M., 2013. Medium-term impact of tillage and residue management on soil aggregate stability, soil carbon and crop productivity. Agric. Ecosyst. Environ. 164, 14–22. https://doi.org/10.1016/j.agee.2012.10.003.
Peña-Angulo, D., Nadal-Romero, E., González-Hidalgo, J.C., Albaladejo, J., Andreu, V., Bagarello, V., Barhi, H., Batalla, R.J., Bernal, S., Bienes, R., Campo, J., Campo-Bescós, M.A., Canatario-Duarte, A., Cantón, Y., Casali, J., Castillo, V., Cerdà, A., Cheggour, A., Cid, P., Cortesi, N., Desir, G., Díaz-Pereira, E., Espigares, T., Estrany, J., Fernández-Raga, M., Ferreira, C.S.S., Ferro, V., Gallart, F., Giménez, R., Gimeno, E., Gómez, J.A., Gómez-Gutiérrez, A., Gómez-Macpherson, H., González-Pelayo, O., Hueso-González, P., Kairis, O., Karatzas, G.P., Klotz, S., Kosmas, C., Lana-Renault, N., Lasanta, T., Latron, J., Lázaro, R., Le Bissonnais, Y., Le Bouteiller, C., Licciardello, F., López-Tarazón, J.A., Lucía, A., Marín, C., Marqués, M.J., Martínez-Fernández, J., Martínez-Mena, M., Martínez-Murillo, J.F., Mateos, L., Mathys, N., Merino-Martín, L., Moreno-de las Heras, M., Moustakas, N., Nicolau, J.M., Novara, A., Pampalone, V., Raclot, D., Rodríguez-Blanco, M.L., Rodrigo-Comino, J., Romero-Díaz, A., Roose, E., Rubio, J.L., Ruiz-Sinoga, J.D., Schnabel, S., Senciales-González, J.M., Simonneaux, V., Solé-Benet, A., Taguas, E. V., Taboada-Castro, M.M., Taboada-Castro, M.T., Todisco, F., Úbeda, X., Varouchakis, E.A., Vericat, D., Wittenberg, L., Zabaleta, A., Zorn, M., 2019. Spatial variability of the relationships of runoff and sediment yield with weather types throughout the Mediterranean basin. J. Hydrol. 571, 390–405. doi:10.1016/j.jhydrol.2019.01.059.
Piccoli, I., Chiarini, F., Carletti, P., Furlan, L., Lazzaro, B., Nardi, S., Berti, A., Sartori, L., Dalconi, M.C., Morari, F., 2016. Disentangling the effects of conservation agriculture practices on the vertical distribution of soil organic carbon. Evidence of poor carbon sequestration in North- Eastern Italy. Agric. Ecosyst. Environ. 230, 68–78. https://doi.org/10.1016/j.agee.2016.05.035.
Potter, K.N., Torbert, H.A., Morrison Jr., J.E., 1995. Tillage and residue effects on infiltration and sediment losses on vertisols. Trans. ASAE 38, 1413–1419. https://doi.org/10.13031/2013.27965.
Reynolds, W.D., Elrick, D.E., 2002. Constant head soil core (tank) method. In: Methods of Soil Analysis. Part, 4. pp. 804–808.
Rhoton, F.E., Shipitalo, M.J., Lindbo, D.L., 2002. Runoff and soil loss from midwestern and southeastern US silt loam soils as affected by tillage practice and soil organic matter content. Soil Tillage Res. 66, 1–11. https://doi.org/10.1016/S0167-1987(02)00005-3.
Romero, P., Castro, G., Gómez, J.A., Fereres, E., 2007. Curve number values for olive orchards under different soil management. Soil Sci. Soc. Am. J. 71, 1758. https://doi.org/10.2136/sssaj2007.0034.
Saco, P.M., Rodríguez, J.F., Moreno-de las Heras, M., Keesstra, S., Azadi, S., Sandi, S., Baartman, J., Rodrigo-Comino, J., Rossi, M.J., 2020. Using hydrological connectivity to detect transitions and degradation thresholds: Applications to dryland systems. Catena 186, 104354. doi:10.1016/j.catena.2019.104354.
Schuller, P., Walling, D.E., Sepúlveda, A., Castillo, A., Pino, I., 2007. Changes in soil erosion associated with the shift from conventional tillage to a no-tillage system, documented using 137Cs measurements. Soil Tillage Res. 94, 183–192. https://doi.org/10.1016/j.still.2006.07.014.
Seta, A.K., Blevins, R.L., Frye, W.W., Barfield, B.J., 1993. Reducing soil erosion and agricultural chemical losses with conservation tillage. J. Environ. Qual. 22, 661. https://doi.org/10.2134/jeq1993.00472425002200040004x.
Shahzad, M., Farooq, M., Hussain, M., 2016. Weed spectrum in different wheat-based cropping systems under conservation and conventional tillage practices in Punjab, Pakistan. Soil Tillage Res. 163, 71–79. https://doi.org/10.1016/j.still.2016.05.012.
Shipitalo, M.J., Edwards, W.M., 1998. Runoff and erosion control with conservation tillage and reduced-input practices on cropped watersheds. Soil Tillage Res. 46, 1–12.
Sun, Y., Zeng, Y., Shi, Q., Pan, X., Huang, S., 2015. No-tillage controls on runoff: A meta-analysis. Soil Tillage Res. 153, 1–6. https://doi.org/10.1016/j.still.2015.04.007.
Tarolli, P., Cavalli, M., Masin, R., 2019. High-resolution morphologic characterization of conservation agriculture. Catena 172, 846–856. https://doi.org/10.1016/j.catena.2018.08.026.
Tarolli, P., Straffelini, E., 2020. Agriculture in Hilly and Mountainous Landscapes: Threats, Monitoring and Sustainable Management. Geogr. Sustain. 1, 70–76. https://doi.org/10.1016/j.geosus.2020.03.003.
TerAvest, D., Carpenter-Boggs, L., Thierfelder, C., Reganold, J.P., 2015. Crop production and soil water management in conservation agriculture, no-till, and conventional tillage systems in Malawi. Agric. Ecosyst. Environ. 212, 285–296. https://doi.org/10.1016/j.agee.2015.07.011.
Thierfelder, C., Wall, P.C., 2009. Effects of conservation agriculture techniques on infiltration and soil water content in Zambia and Zimbabwe. Soil Tillage Res. 105, 217–227. https://doi.org/10.1016/j.still.2009.07.007.
Tiessen, K.H.D., Elliott, J.A., Yarotski, J., Lobb, D.A., Flaten, D.N., Glozier, N.E., 2010. Conventional and conservation tillage: influence on seasonal runoff, sediment, and nutrient losses in the Canadian prairies. J. Environ. Qual. 39, 964. https://doi.org/10.2134/jeq2009.0219.
Topp, G.C., Ferré, P.A., Dane, J.H., 2002. Water content. In: Methods of Soil Analysis. Part, 4. pp. 417–545.
Vaezi, A.R., Zarrinabadi, E., Auerswald, K., 2017. Interaction of land use, slope gradient and rain sequence on runoff and soil loss from weakly aggregated semi-arid soils. Soil Tillage Res. 172, 22–31. https://doi.org/10.1016/j.still.2017.05.001.
Wang, J., Lü, G., Guo, X., Wang, Y., Ding, S., Wang, D., 2015. Conservation tillage and optimized fertilization reduce winter runoff losses of nitrogen and phosphorus from farmland in the Chaohu Lake region. China. Nutr. Cycl. Agroecosystems 101, 93–106. https://doi.org/10.1007/s10705-014-9664-3.
Wang, L., Dalabay, N., Lu, P., Wu, F., 2017. Effects of tillage practices and slope on runoff and erosion of soil from the Loess Plateau, China, subjected to simulated rainfall. Soil Tillage Res. 166, 147–156. https://doi.org/10.1016/j.still.2016.09.007.
Zhang, G., Chan, K., Oates, A., Heenan, D., Huang, G., 2007. Relationship between soil structure and runoff/soil loss after 24 years of conservation tillage. Soil Tillage Res. 92, 122–128. https://doi.org/10.1016/j.still.2006.01.006.
Zhao, X., Chen, X., Huang, J., Wu, P., Helmers, M.J., 2014. Effects of vegetation cover of natural grassland on runoff and sediment yield in loess hilly region of China. J. Sci. Food Agric. 94, 497–503. https://doi.org/10.1002/jsfa.6275.