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RESEARCH ARTICLE

Conservation tillage and organic farming reduce soil erosion

Steffen Seitz[1] · **Philipp Goebes**[1] · **Viviana Loaiza Puerta**[2] · **Engil Isadora Pujol Pereira**[3] · **Raphaël Wittwer**[4] · **Johan Six**[2] · **Marcel G. A. van der Heijden**[4,5] · **Thomas Scholten**[1]

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Abstract

The impact of different arable farming practices on soil erosion is only partly resolved, and the effect of conservation tillage practices in organic agriculture on sediment loss has rarely been tested in the field. This study investigated rainfall-induced interrill sediment loss in a long-term replicated arable farming system and tillage experiment (the FAST trial) with four different cropping systems: (1) organic farming with intensive tillage, (2) organic farming with reduced tillage, (3) conventional farming with intensive tillage, and (4) conventional farming with no tillage. Measurements were carried out under simulated heavy rainfall events with runoff plots in 2014 (fallow land after winter wheat) and 2017 (during maize growth). Organic farming decreased mean sediment delivery compared to conventional farming by 30% (0.54 t ha^{-1} h^{-1}). This study demonstrated that reduced tillage in organic farming decreased sediment delivery (0.73 t ha^{-1} h^{-1}) compared to intensively tilled organic plots (1.87 t ha^{-1} h^{-1}) by 61%. Nevertheless, the combination of conventional farming and no tillage showed the lowest sediment delivery (0.24 t ha^{-1} h^{-1}), whereas intensively tilled conventional plots revealed the highest delivery (3.46 t ha^{-1} h^{-1}). Erosion rates were much higher in June during maize growth (2.92 t ha^{-1} h^{-1}) compared to those of fallow land after winter wheat (0.23 t ha^{-1} h^{-1}). Soil surface cover and soil organic matter were the best predictors for reduced sediment delivery, and living plant cover from weeds in reduced organic treatments appeared to protect soil surfaces better than plant residues in conventional, no-tillage plots. Soil erosion rates were significantly lower when soil cover was above 30%. In conclusion, this study demonstrates that both organic farming and conservation agriculture reduce soil losses and showed for the first time that reduced tillage practices are a major improvement in organic farming when it comes to soil erosion control.

Keywords Soil loss · Organic farming · Conservation agriculture · Arable cropping · Soil protection · Rainfall simulation · Runoff plots

1 Introduction

Soil erosion is a major environmental problem with severe impacts on terrestrial and fluvial ecosystems (Smith et al. 2016). Verheijen et al. (2009) indicated that 3 to 40 t ha^{-1} of soil material is eroded in Europe every year, whereas mean soil formation rates do not exceed 0.3 to 1.4 t ha^{-1}. It is well established that agricultural practices greatly influence soil erosion (Montgomery 2007). In particular, the intensification of cultivation after World War II led to increased soil losses (Matson 1997). In this context, conventional farming strategies have drawn criticism (Gomiero 2013), because they often lead to diminished topsoil depth, degraded soil structure, soil compaction, losses of soil organic matter (SOM), and nutrient depletion (Morgan 2005). As a consequence, crop yields can be reduced and fields rendered unproductive over the long term (Bünemann et al. 2018).

Marcel G. A. van der Heijden and Thomas Scholten are joint last authors

✉ Steffen Seitz
steffen.seitz@uni-tuebingen.de

[1] Soil Science and Geomorphology, Institute of Geography, Department of Geosciences, University of Tübingen, Rümelinstrasse 19-23, 72070 Tübingen, Germany

[2] Institute of Agricultural Sciences, Department of Environmental Systems Science, Swiss Federal Institute of Technology, ETH Zürich, 8092 Zürich, Switzerland

[3] School of Earth, Environmental, and Marine Sciences, University of Texas Rio Grande Valley, Edinburg, TX 78539, USA

[4] Research Division Agroecology and Environment, Agroscope Federal Office for Agriculture, 8046 Zürich, Switzerland

[5] Department of Plant and Microbial Biology, University of Zürich, 8057 Zürich, Switzerland

Besides conventional farming systems, alternative strategies like organic farming are of growing interest (Gomiero et al. 2011a; Reganold and Wachter 2016). Even if "organic farming" appears to be a broadly used term, it is regulated by different certifying institutional bodies and generally relies on crop rotation, absence of synthetic agrochemicals, and weed control without herbicides (Gomiero et al. 2011b). Although organic farming practices often lead to reduced crop yields (Ponisio et al. 2014; Wittwer et al. 2017), they can increase soil fertility and are associated with increased biological diversity (Hole et al. 2005; Verbruggen et al. 2010; Knapp and van der Heijden 2018). Furthermore, organic farming practices generally enhance soil surface cover (Reganold et al. 1987) and improve soil structure by stabilizing soil aggregation (Erhart and Hartl 2009). Several studies showed higher SOM contents in the topsoil layer on arable land under organic farming than conventional land use, which is a factor that can positively affect soil stabilization (Six et al. 2000a; Ghabbour et al. 2017).

Furthermore, studies showed that organic farming has the potential to diminish soil erosion (Erhart and Hartl 2009). Most of those studies are based on models such as the Universal Soil Loss Equation (USLE, empirical) or the Water Erosion Prediction Project (WEPP, process-based) (Lockeretz et al. 1981; Reganold 1988; Auerswald et al. 2003; Pacini et al. 2003; Arnhold et al. 2014). Some studies indirectly assessed soil erosion by evaluating topsoil thickness (Reganold et al. 1987), soil erodibility (Fleming et al. 1997; Siegrist et al. 1998; Kuhn et al. 2012), aggregate stability (Mulla et al. 1992; Pulleman et al. 2003), or nutrients in runoff of farm drainage systems (Eltun et al. 2002) and one study directly assessed soil erosion in organically versus conventionally managed plots (Weilgart Patten 1982) using the Alutin rill method. Even if it can be stated that erosion models have originally been calibrated with field data, there is a general lack of experimental in situ measurements to compare organic farming systems (Gomiero 2013). In particular, experimental research with comparable conditions (e.g., in soil type and texture) for both organic and conventional treatments is scarce (Reganold 1988; Auerswald et al. 2003).

A number of studies revealed that conservation tillage (any tillage system that maintains at least 30% of cover on the soil surface, e.g., reduced or no tillage, cf. Soil Science Society of America 2008) decreases soil erosion and improves soil structure (Six et al. 2000b; Zhang et al. 2007; Erhart and Hartl 2009), but might also increase soil compaction in organic farming (Peigné et al. 2018). The advantage of reduced or no tillage systems is a higher soil surface cover throughout the year and better protection of soil structure or structure-forming soil organisms such as earthworms (Mikha and Rice 2004; Blanco-Canqui and Lal 2008). The benefits of these practices increase further when combined with diverse crop rotation (Pittelkow et al. 2015) and permanent soil cover to protect topsoils against particle detachment (Durán Zuazo and Rodríguez Pleguezuelo 2008; Goebes et al. 2014). Reduced tillage does not abandon all mechanical operations for seedbed preparation, but minimizes tillage operations to the smallest frequency (e.g., for weed control in organic farming) necessary to guarantee crop growth (Soil Science Society of America 2008). There is an increasing interest to apply conservation tillage practices under organic conditions (Armengot et al. 2015; Cooper et al. 2016), but to our knowledge, the impact of organic farming in combination with reduced tillage on soil erosion has not yet been tested. Moreover, it is still unclear how conservation or no tillage under conventional conditions compares to tilled organic systems. Thus, research on this topic is important to evaluate and potentially improve soil erosion control in different farming systems (Hösl and Strauss 2016).

This study investigated soil erosion rates under simulated heavy rainfall events in situ in the Swiss Farming System and Tillage experiment (FAST, Prechsl et al. 2017; Wittwer et al. 2017; Hartman et al. 2018), a replicated and randomized field experiment with four major arable cropping systems (organic–intensive tillage, organic–reduced tillage, conventional–intensive tillage, conventional–no tillage). Hence, we could compare these cropping systems directly without confounding factors such as differences in soil type, crop type, or crop rotation history. A portable rainfall simulator was used to dose precipitation over micro-scale runoff plots (ROP) in the field (Fig. 1). Subsequently, sediment delivery after simulated rainfall events was collected. This method has proven reliable in rough terrain conditions and is highly suitable to measure interrill soil erosion in replicated field experiments (Seitz 2015).

We hypothesized that:

I. Organic farming reduces soil erosion when compared to conventional farming systems, as a consequence of higher soil surface cover and SOM content under organic farming.
II. A reduction of tillage intensity in organic farming further reduces soil erosion compared to intensive tillage practices.

2 Materials and methods

2.1 Experimental design

This study took place at the FAST experiment of Agroscope near Reckenholz, Zürich, Switzerland (47° 26′ 20″ N, 8° 31′ 40″ E), which has a humid and continental climate (Köppen-Geiger classification: Dfb) with a mean temperature of 9.4 °C and an annual precipitation of 1054 mm (1981–2010).

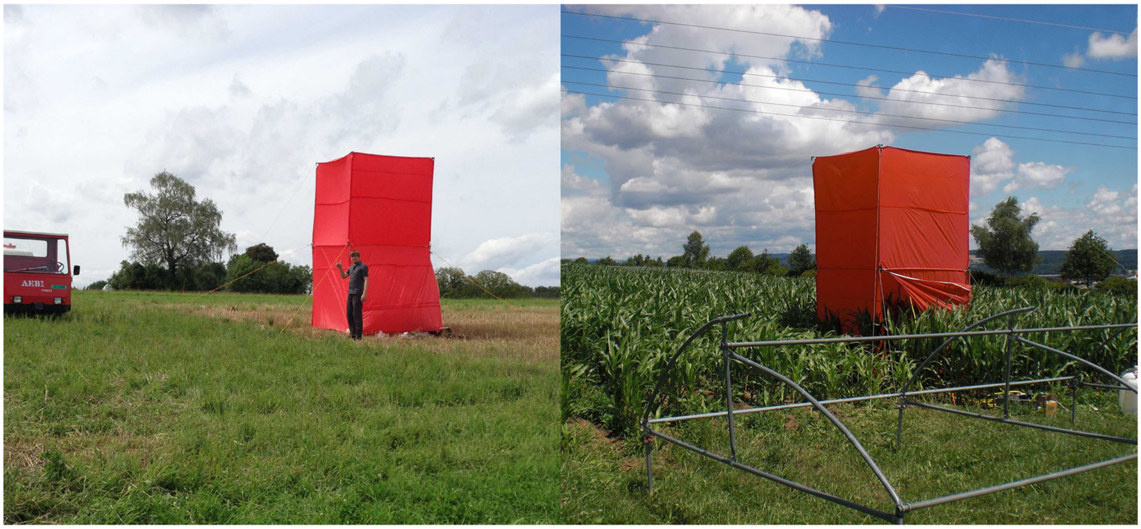

Fig. 1 The Tübingen rainfall simulator at the Swiss Farming System and Tillage experiment (FAST Agroscope) near Reckenholz, Zürich, in 2014 (left) and 2017 (right)

According to the Swiss Severe Weather Database (SSWD), heavy rainfall events in this area can reach intensities of more than 70 mm h^{-1}. In 2014 and 2017, respectively, seven and nine events exceeded an intensity of 50 mm h^{-1}. Mean slope of the study site is 6°. The soil is a loamy Cambisol (clay 23%, silt 34%, sand 43%) on glacially deposited Pleistocene sediments (according to the World Reference Base for Soil Resources, WRB 2015). The experimental field consists of two adjacent trials (FAST I and FAST II) following a staggered start design with FAST I set up in 2009 and FAST II in 2010. Each trial was arranged in a randomized block design with 16 experimental plots (6 m × 30 m each) per block and four replicates (Wittwer et al. 2017). The experimental factors were organic (O) and conventional (C) farming system, as well as the tillage system with intensive tillage (IT) and plots with reduced (RT) or no tillage (NT), resulting in a management treatment with four combinations: organic–intensive tillage (O-IT), organic–reduced tillage (O-RT), conventional–intensive tillage (C-IT), and conventional–no tillage (C-NT). Organic farming was conducted according to the Bio Suisse guidelines of the federation of Swiss organic farmers and conventional farming following the “Proof of Ecological Performance” guidelines of the Swiss Federal Office for Agriculture (Wittwer et al. 2017). Organic–no tillage was not tested in view of expected problems with weed control (Gomiero et al. 2011a).

In the IT system, tillage was carried out to a depth of 0.2 m with a moldboard plow (Menzi B. Schnyder Pflugfabrik, Brütten, Switzerland) followed by seedbed preparation with a rotary harrow (Amazone, H. Dreyer, Hasbergen, Germany) to a depth of 0.05 m. Organic RT was carried out by a disk and a rotary harrow (first crop rotation) to a depth of 0.05 m as well as a plane iron (“Geohobel,” Rath Maschinen, Maria Rojach, Austria) to a depth of 0.03 m. No soil disturbance was applied in the NT plots. As herbicides are prohibited in organic farming systems, superficial soil disturbance was necessary for weed control (Gomiero et al. 2011a; Wittwer et al. 2017). Conversely, post-emergence herbicides as well as glyphosate (only in C-NT) were used in the conventional farming system. Soil fertility management also differed: mineral fertilizers were applied to the conventional systems while cattle slurry was applied to the organic systems (Hartman et al. 2018). In addition to the management treatment, four cover crop treatments (brassica, legume, mixture, and no cover crop as control) were established as subplots in the first 2 years of the 6-year crop rotation with sequencing winter wheat, maize, field bean, winter wheat, and two times grass-clover (for more details about crop rotation, see Wittwer et al. 2017). All soil erosion measurements in this study were carried out in the control treatment without cover crop.

2.2 Field and laboratory measurements

The determination of sediment delivery was performed using the portable Tübingen rainfall simulator (Fig. 1) with runoff plots (ROPs, 0.4 m × 0.4 m) following Seitz et al. (2016). Micro-scale ROPs suitably compare influences of different treatments on interrill soil erosion processes under homogenous site conditions (Wainwright et al. 2000) with a high number of replications (Hudson 1993). Each experimental plot was equipped with two ROPs and measurements were conducted in two different years: (1) in August 2014 on fallow land 1 week after harvesting winter wheat in FAST II, and (2) in June 2017 in a maize stand (growth-stage BBCH 35 stem elongation) in FAST I (Wittwer et al. 2017). The two points in time represent two different risk periods: fallow land after cereal harvest prone to heavy summer and early fall precipitation events, and maize prone to spring and early summer precipitation events.

With four treatments, four replicates per treatment and two ROPs per replicate, the number of ROPs resulted in a total of 32 randomly distributed ROPs per year ($n = 64$). A portable, single nozzle rainfall simulator, calibrated with a laser precipitation monitor (Thies GmbH, Göttingen, Germany), generated a standardized rain spectrum under a protective tent (Iserloh et al. 2013; Seitz et al. 2015). A heavy rainfall event (60 mm h^{-1}) was simulated for 30 min on every ROP with a mean kinetic energy expenditure of 475 J m^{-2} h^{-1}. Runoff and sediment delivery were collected in 2-l bottles and filtrated on fiberglass filters. Sediment was oven-dried (40 °C) before weighing. Slope was measured at every ROP with a clinometer, soil surface cover was determined photogrammetrically (grid quadrat method with GIMP 2.8), and initial soil moisture content was measured before every rainfall simulation with a WET-2 sensor (Delta-T Devices, Cambridge, UK). Bulk soil density (0 to 0.06 m) was quantified with the mass-per-volume method (Blume et al. 2010). Soil organic carbon was determined with an elemental analyzer (LECO, MI, USA) and converted to SOM in grams per kilogram of soil (depth 0 to 0.06 m). Aggregate sizes were obtained by wet sieving and reported as mean weight diameter (MWD, van Bavel 1950).

2.3 Data analyses

Generalized additive mixed (GAM) models with restricted maximum likelihood and smoothness estimation (Gaussian) by an unbiased risk estimator (UBRE) were used to assess the influences of different farming and tillage systems as well as soil and terrain attributes on interrill soil erosion. Sediment delivery was fitted against management treatment (O, C, NT, RT, IT), SOM, surface cover, initial soil moisture, bulk soil density, and MWD as fixed effects and slope, plot, and block as random factors. In further models, management treatment was fitted against surface cover, while management treatment, MWD, bulk soil density, and slope were fitted against SOM using plot and block as random factors, respectively. Moreover, one-way ANOVAs were fitted and contrasts (post hoc) were used with Tukey's HSD test to investigate differences among means of the four treatment combinations in both years together as well as separated into 2014 and 2017. The data was scaled and response variables were square-root-transformed before conducting statistical analyses. The residuals did not show irregularities in normality or homogeneity of variances. Analyses were performed with the R-packages "multcomp" (Westfall 1999) and "mgcv" (Wood 2011) in R 3.1.2 (R Development Core Team 2014).

Data availability The dataset generated during the current study is available from the corresponding author on reasonable request.

3 Results and discussion

3.1 Measurement outcome

Sediment delivery was significantly affected by the management treatment (Table 1). Organic treatments decreased mean sediment delivery by 30% or 0.54 t ha^{-1} h^{-1} compared to conventional treatments. This finding was also confirmed separately in 2014 (54%, 0.17 t ha^{-1} h^{-1}) and 2017 (27%, 0.92 t ha^{-1} h^{-1}). Overall erosion rates in 2017 were much higher compared to values observed in 2014 (Table 2).

Conservation tillage decreased sediment delivery by 82% or 2.17 t ha^{-1} h^{-1} compared to intensively tilled plots for both years combined. Likewise, sediment delivery was decreased by 56% (0.18 t ha^{-1} h^{-1}) in 2014 and by 83% (4.17 t ha^{-1} h^{-1}) in 2017 (Table 2). In 2014, the combination of organic farming and reduced tillage (O-RT) showed the lowest sediment delivery (Fig. 2), whereas intensively tilled conventional treatments (C-IT) showed the highest rates. Both treatments significantly deviated from the mean across all other treatments ($p < 0.001$). The conventional–no tillage (C-NT) treatments revealed similar erosion rates to intensive tillage organic treatments (O-IT) in this year.

In 2017, C-IT still showed the highest sediment delivery followed by O-IT (Fig. 2). In contrast to 2014, O-RT performed less good regarding sediment delivery in 2017 and C-NT showed the lowest erosion rates, but on the same level as that in 2014. All four treatments deviated significantly from each other. This pattern was also confirmed for total soil erosion rates over both years (Fig. 2).

Of the investigated continuous variables, soil surface cover had the highest influence on soil erosion and decreased sediment delivery when soil surfaces were covered by more than 30% (Table 1 and Fig. 3). It was affected by the tillage treatment with NT having the most important influence ($t = 4.5$, $p < 0.001$). In 2014 (mean = 85%), soil surface cover in O-RT, C-NT, O-IT, and C-IT was 98% (SE = 1.8), 94% (SE = 4.9), 79% (SE = 6.4), and 71% (SE = 10.9), respectively. In 2017, soil surface cover was considerably lower (mean = 30%), and in C-NT, O-RT, O-IT, and C-IT was 97% (SE = 1.3), 16% (SE = 6.0), 3% (SE = 1.0), and 2.5% (SE = 2.1), respectively.

Furthermore, SOM content influenced sediment delivery (Table 1). SOM was affected by the tillage treatment with RT having the most important influence ($t = 2.2$, $p < 0.05$). In 2014 (mean = 37.7 g kg^{-1}, SE = 8.3), SOM was 37.9 g kg^{-1} (SE = 8.6) in O-RT, 36.6 g kg^{-1} (SE = 3.9) in C-IT, 35.9 g kg^{-1} (SE = 10.7) in O-IT, and

Table 1 Results of the generalized additive mixed model (GAM) with restricted maximum likelihood and smoothness estimation (UBRE) for sediment delivery in the Swiss Farming System and Tillage (FAST) experiment near Reckenholz, Zürich ($n = 64$)

		t value	Pr
Fixed effects	Management treatment	3.23	0.002**
	Soil organic matter	2.23	0.030*
	Surface cover	5.01	< 0.001***
	Initial moisture	1.74	0.089 n.s.
	Bulk soil density	0.56	0.578 n.s.
	Mean weight diameter (soil aggregation)	1.65	0.105 n.s.
Random factors		Slope, plot, block	
Rating		adj. $R^2 = 0.81$, deviance explained = 83%	

n.s. not significant

***$p < 0.001$; **$p < 0.01$; *$p < 0.05$

29.7 g kg^{-1} (SE = 5.7) in C-NT, whereas it was generally higher in 2017 (mean = 40.4 g kg^{-1}, SE = 9.4) with 46.6 g kg^{-1} (SE = 11.8) in O-RT, 43.0 g kg^{-1} (SE = 5.8) in C-NT, 36.1 g kg^{-1} (SE = 8.6) in C-IT, and 36.0 g kg^{-1} (SE = 5.0) in O-IT at the time of measurements.

The MWD of soil aggregates was higher in 2014 (mean = 1.01 mm, SE = 0.14) than that in 2017 (mean = 0.64 mm, SE = 0.09) at the time of measurements. Neither MWD (overall mean = 0.81, SE = 0.21) nor bulk soil density (mean = 1.25 g cm^{-3}, SE = 0.02) nor initial soil moisture (mean = 17.9%, SE = 0.5) affected sediment delivery (Table 1).

3.2 The effect of organic farming on soil erosion

Several studies reported that organic farming has a positive effect on biodiversity (Mäder et al. 2002; Verbruggen et al. 2010), soil carbon sequestration (Gattinger et al. 2012), and environmental sustainability (Reganold and Wachter 2016). Additionally, earlier studies based on erosion modeling and comparison of different field sites with variable farming systems indicated that organic farming practices can reduce soil erosion (Lockeretz et al. 1981; Auerswald et al. 2003; Pacini et al. 2003; Arnhold et al. 2014). This study demonstrated that organic farming reduces soil erosion in a Swiss farming system and tillage experiment in a humid and continental climate using a comparative field experiment without external parameterization. Thus, it provides experimental evidence in situ based on a replicated field design and excluding confounding factors such as differences in soil types, land use history, or crop rotation between organically and conventionally managed plots. This finding is especially relevant for regions vulnerable to soil erosion, such as steep agricultural landscapes and areas with intense precipitation. During a single heavy rainfall event in this experiment, interrill sediment delivery in organic plots was, on average, reduced by 0.54 t ha^{-1} h^{-1} compared to conventionally managed counterparts. Thus, the level of soil erosion control observed in the FAST experiment can make the difference between sustainable and unsustainable agriculture sensu Montgomery (2007). This result is even more important, if the early stage of the field trial is taken into account. FAST started only 4 years before the first erosion measurement and differences between treatments may accentuate with time.

An earlier study by Reganold et al. (1987) indicated that organic farming can have a long-term, erosion-reducing effect. The results of that study based on a comparison of two farms indicated that higher SOM content and a thicker topsoil layer in the organically managed plots were responsible for a reduction of sediment delivery. Increasing SOM proved to effectively reduce soil erosion in general (Ghabbour et al. 2017), and an erosion-reducing effect of SOM was also confirmed by the present study. Moreover, SOM increased considerably in FAST from 2014 to 2017 and was the highest in O-RT in both years. This finding could be explained by the 2-year grass-clover ley that was grown between winter wheat and maize within the FAST rotation and is known to increase SOM in agricultural soils (Loaiza Puerta et al. 2018). The increased SOM content in the topsoil layer in O-RT might be attributed to the combined effect of organic fertilization and reduced tillage intensity. SOM is one of the key factors that affect aggregate stability and size

Table 2 Sediment delivery in 2014 and 2017 and the average for both years for four management treatments in the Swiss Farming System and Tillage (FAST) experiment near Reckenholz, Zürich ($n = 64$)

	Sediment delivery (t ha^{-1} h^{-1})		
Treatment	2014	2017	Total
Conventional	0.32	3.38	1.85
Organic	0.15	2.46	1.30
Intensive tillage	0.32	5.01	2.66
Conservation tillage (NT and RT)	0.14	0.83	0.49
Mean	0.23	2.92	1.58

NT no tillage, *RT* reduced tillage

by binding soil particles (and small aggregates) together (Six et al. 2000b; Blanco-Canqui and Lal 2008), a twofold interaction in which SOM stabilizes aggregates and aggregates in turn stabilize SOM (Six et al. 1999). Nevertheless, MWD did not show an effect on soil erosion in this experiment, which could be attributed to tillage operations closely before measurements in 2017 (see next paragraph). In this experiment, cattle slurry was applied as fertilizer in organically managed plots whereas mineral fertilizer was used in the conventionally managed plots. Earlier studies showed that animal manure can improve soil aggregation and soil structure stability (Green et al. 2005), and differences in soil erosion rates between organic and conventional plots could, at least in part, be due to this difference in fertilization. Moreover, the biomass and density of earthworms, which play an important role for soil structure formation (Siegrist et al. 1998), were found to be higher in organic plots compared to those in conventional plots in FAST (unpublished results, cf. Pfiffner and Mäder 1997), which is another possible explanation for differences in soil erosion rates. Lastly, soil surface cover represented the most important factor to reduce soil erosion, which was expected from general literature (Thornes 1990; Blanco-Canqui and Lal 2008). In this context, a clear difference between the two risk periods (fallow in late summer 2014 and maize in summer 2017) was detectable with much higher interrill sediment delivery in maize, where soil cover was much lower. Maize is known to increase soil losses not only because of wide interrow spaces, but also of its specific plant architecture (Blanco-Canqui and Lal 2008). In general, soil surface cover was clearly influenced by the management treatment and soil inversion by plowing and in particular mechanical weed control in organically managed plots affected soil surface cover importantly (Wittwer et al. 2017).

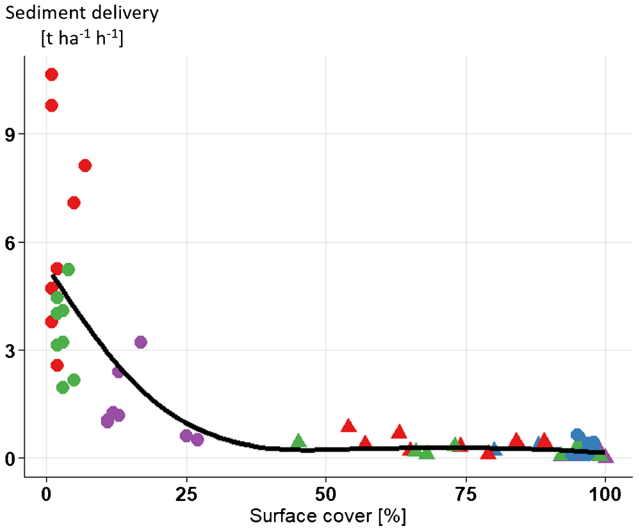

Fig. 3 Surface cover affects sediment delivery (t ha^{-1} h^{-1}) in 2014 (triangles) and 2017 (dots) at the Swiss Farming System and Tillage (FAST) experiment near Reckenholz, Zürich (*n* = 64). Different colors represent different farming treatments: red, conventional–intensive tillage (C-IT); blue, conventional–no tillage (C-NT); green, organic–intensive tillage (O-IT); and purple, organic–reduced tillage (O-RT). The black line represents the result of a generalized additive model (GAM)

3.3 The effect of reduced tillage on soil erosion in organic farming

The use of reduced tillage in organic farming systems improves soil quality compared to intensive tillage (Cooper

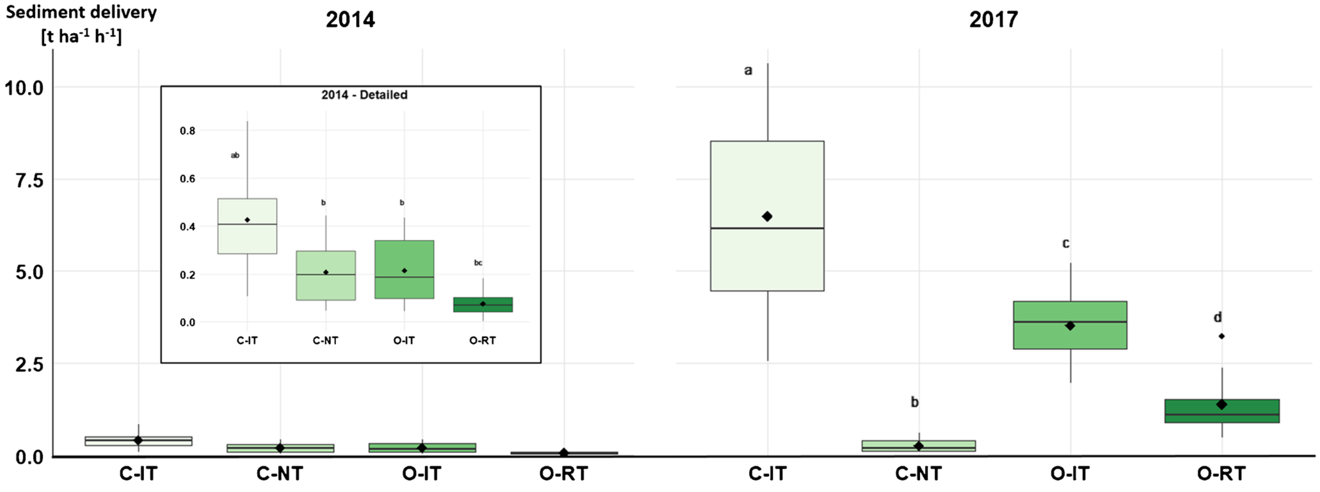

Fig. 2 Sediment delivery (t ha^{-1} h^{-1}) on four treatment combinations (C-IT, conventional–intensive tillage; C-NT, conventional–no tillage; O-IT, organic–intensive tillage; O-RT, organic–reduced tillage) in 2014 and 2017 at the Swiss Farming System and Tillage (FAST) experiment near Reckenholz, Zürich (*n* = 64). Diamonds represent mean values and lines within boxplots represent median values. Small letters represent significant differences in mean values

et al. 2016), but comparative studies on this topic in general and investigations on soil erosion in particular are sparse (Teasdale et al. 2007; Barré et al. 2018). In this study, the introduction of reduced tillage significantly decreased soil erosion compared to intensively tilled organic farming. In 2014, O-RT showed the lowest soil erosion rates and performed even better than C-NT. Moreover, C-NT revealed a consistent erosion protection with similar low rates in both years. The opposite is true for conventional farming with intensive tillage practices, which showed the highest erosion rates in both years. From a soil conservation perspective, reducing tillage operations will further improve the ecological impact of organic farming systems. This finding supports Arnhold et al. (2014), who suggested that organic farming requires additional conservation measures to provide an effective control of soil erosion, especially in steep terrain conditions.

Bradford and Huang (1994) ascribed the positive effect of conservation tillage on soil erosion control to a continuous soil surface cover (cf. Montgomery 2007), as well as greater soil strength and resistance against detachment (cf. Gebhardt et al. 1985) with both reduced and no tillage. It was shown that a longer lasting soil surface cover throughout the year is one of the main contributions of conservation tillage to soil protection (Blanco-Canqui and Lal 2008). The previous year's residue generally reduces soil disturbances and downslope movements of soil particles (Ranaivoson et al. 2017). Our study underpinned the latter and underlined the principles of conservation agriculture that a minimum soil cover of 30% is required (cf. Soil Science Society of America 2008), which was also identified in our study as a threshold for an effective protection against soil erosion. Interestingly, in 2014, we could further show that reduced tillage in organic farming can be more effective in countering sediment delivery than no tillage in conventional farming. In 2014, a serious weed infestation occurred in summer that could not be tackled by mechanical operations (unpublished results, cf. Wittwer et al. 2017). Thus, soil cover in RT after harvest consisted not only of straw residues, but also of living plants (weeds: *Agropyron repens*, *Poa annua*, *Poa trivialis*, *Papaver rhoeas*, *Polygonum aviculare*, among others), whereas soil cover in NT solely consisted of dead plant residues, which appeared to be less effective to counter soil erosion.

In 2017 and without weed infestation, NT proved its positive impact on soil protection due to a more intact soil structure and a continuous soil surface cover (Durán Zuazo and Rodríguez Pleguezuelo 2008). Nevertheless, a certain amount of tillage operations is necessary in organic farming for weed control, because herbicides are not used (Gomiero et al. 2011a). As such, the use of plows down to a depth of 0.2 m favors sediment delivery more than shallow non-inverting tillage. Generally, reduced tillage operations need to be precisely adjusted and balanced for an effective control of soil erosion in organic farming systems. In our case, O-RT still reduced sediment delivery by 61% compared to O-IT in erosion-prone maize stands in 2017.

Loaiza Puerta et al. (2018) reported that organic management together with reduced tillage significantly improved the soil structure in the FAST experiment. Conservation tillage can promote aggregation of microaggregates into macroaggregates compared to intensive tillage (Six et al. 2000b), and macroaggregate turnover is lower under reduced tillage (Six et al. 2000a). Green et al. (2005) found that the potential loss of microaggregates through sediment transport is higher on tilled organic treatments than on no-tillage treatments. Nevertheless, MWD of soil aggregates did not show an effect on soil erosion in this experiment and was lower in 2017 than that in 2014 at the time of measurements.

4 Conclusion

This study enabled ranking four different arable cropping systems regarding soil erosion and showed for the first time in situ that the application of reduced tillage in organic farming can further decrease sediment delivery. Thus, it appears to be a major improvement for soil erosion control in organic farming systems. The experiment demonstrated that reduced soil erosion in organic agriculture compared to conventional agriculture was mainly driven by soil surface cover and SOM. Additionally, this work showed that a living plant cover from weeds can reduce soil erosion more effectively compared to dead plant residues in conventional, no-tillage systems.

Further research is required on factors influencing soil erosion in organic farming systems in order to apply them generally. Such research should include other types of organic farming with different cultivation and manure regimes on different substrates and within different climates. It should also cover the influences of microorganisms on aggregation, especially the impact of arbuscular mycorrhizal fungi (AMF), a group of soil fungi known to influence soil structure (van der Heijden et al. 2006). Finally, it is of high interest to conduct further research on the effects of reduced tillage techniques on different types of organic farming systems and their individual application in different environments (Cooper et al. 2016). In this context, the consideration of reduced tillage within strategies to increase yields in organic farming becomes of importance, as those strategies will most of all contribute to the general acceptance of organic principles in farming (Röös et al. 2018).

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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