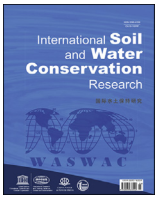
International Soil and Water Conservation Research 10 (2022) 188–196

Contents lists available at ScienceDirect

International Soil and Water Conservation Research

journal homepage: www.elsevier.com/locate/iswcr



Original Research Article

Conservation management decreases surface runoff and soil erosion

Xuan Du [a], Jinshi Jian [b, c, *], Can Du [d], Ryan D. Stewart [e]

[a] *Department of Hydraulic Engineering, Yangling Vocational & Technical College, Yang Ling, Shaanxi, China*
[b] *State Key Laboratory of Soil Erosion and Dryland Farming on the Loess Plateau, Northwest A&F University, Yangling, 712100, China*
[c] *Pacific Northwest National Laboratory-University of Maryland Joint Global Change Research Institute, 5825 University Research Court, Suite, 3500, College Park, MD, USA*
[d] *Department of Bioengineering, Yangling Vocational & Technical College, Yang Ling, Shaanxi, China*
[e] *School of Plant and Environmental Sciences, Virginia Tech, Blacksburg, VA, USA*

ARTICLE INFO

Article history:
Received 8 February 2021
Received in revised form
3 August 2021
Accepted 7 August 2021
Available online 9 August 2021

Keywords:
Conservation management
Soil erosion
Runoff
Meta-analysis
Soil health

ABSTRACT

Conservation management practices – including agroforestry, cover cropping, no-till, reduced tillage, and residue return – have been applied for decades to control surface runoff and soil erosion, yet results have not been integrated and evaluated across cropping systems. In this study we collected data comparing agricultural production with and without conservation management strategies. We used a bootstrap resampling analysis to explore interactions between practice type, soil texture, surface runoff, and soil erosion. We then used a correlation analysis to relate changes in surface runoff and soil erosion to 13 other soil health and agronomic indicators, including soil organic carbon, soil aggregation, infiltration, porosity, subsurface leaching, and cash crop yield. Across all conservation management practices, surface runoff and erosion had respective mean decreases of 67% and 80% compared with controls. Use of cover cropping provided the largest decreases in erosion and surface runoff, thus emphasizing the importance of maintaining continuous vegetative cover on soils. Coarse- and medium-textured soils had greater decreases in both erosion and runoff than fine-textured soils. Changes in surface runoff and soil erosion under conservation management were highly correlated with soil organic carbon, aggregation, porosity, infiltration, leaching, and yield, showing that conservation practices help drive important interactions between these different facets of soil health. This study offers the first large-scale comparison of how different conservation agriculture practices reduce surface runoff and soil erosion, and at the same time provides new insight into how these interactions influence the improvement or loss of soil health.

1. Introduction

Soil is a dynamic, living resource that is essential to the sustainable production of food and fiber and to the maintenance of global biogeochemical cycling and ecosystem functioning. However, many cropland soils suffer from severe degradation (Bridges & Van Baren, 1997; Harwood, 1990). Soil erosion, often driven by excess surface runoff, is a key cause of this degradation by removing topsoil along with the organic matter and other nutrients held within it (Biddoccu et al., 2016). Croplands worldwide experience higher erosion rates than other land uses (García-Ruiz et al., 2015). Famous examples of pervasive and persistent erosion include the Dust Bowl that formed in the Great Plains of the USA during the 1930s and caused extensive ecological damage and economical losses (Schubert et al., 2004), large-scale gully formation in the Piedmont region of the southeastern USA that devastated the ability of those lands to support crop production (Galang et al., 2007), and widespread soil losses within the Loess plateau of China that currently contribute approximately 90% of sediment to the Yellow River (Zhao et al., 2013). Other areas of China also suffer from widespread erosion, including the black soil region in the northeast (Wang & Li, 2018) and the red soil region in the south of the country (Deng et al., 2019). In summary, soil erosion can cause direct economic losses, declines in crop yields, and increases in crop production costs, in some cases leading to farm

---

* Corresponding author. State Key Laboratory of Soil Erosion and Dryland Farming on the Loess Plateau, Northwest A&F University, Yangling, 712100, China.
E-mail address: jinshi@vt.edu (J. Jian).

https://doi.org/10.1016/j.iswcr.2021.08.001

abandonment (Ran et al., 2013).

Conservation agricultural practices have been developed to reduce soil degradation and improve cropland productivity. Relevant practices include agroforestry (AF), reduced tillage (RT), no-till (NT), cover cropping (CC), and residue return (RR). Such practices are designed to provide benefits to soil, water, and agroecosystems, mainly by reducing soil disturbance, increasing surface coverage by plants and their residues, enhancing biodiversity, and maximizing the presence and extent of living roots (Terra et al., 2005; Busari et al., 2015; Stott & Moebius-Clune, 2017). Many field experiments have evaluated how these conservation practices affect surface runoff and soil erosion (Cooper et al., 1996; König, 1992; Kusumandari & Mitchell, 1997; Reganold et al., 1993; Shi et al., 2018; Yong, 1989). For example, the presence of tree stems in AF systems can reduce runoff velocities and thereby decrease the sediment carrying capacity (Lal, 1989), while the increase in surface litter associated with perennial plants can help to reduce splash and soil detachment (Fu et al., 1995). Including CC during fallow seasons can increase soil surface coverage, provide additional surface roughness, raise rainfall retention time, and improve plant root penetration depths, all of which can form positive feedbacks to control excess surface runoff and erosion (Berhe et al., 2007; Kaye & Quemada, 2017; Meyer et al., 1997). Decreasing or avoid ploughing under reduced- and no-till practices can protect soil by preserving soil organic matter, which can help bind soil particles and prevent slaking and disaggregation (Karlen et al., 2013; Puget & Lal, 2005; Sainju et al., 2002). Residue return, in which standing or cut residue is left on the soil surface, provides better surface cover and roughness, thus reducing erosive potential of surface water (Lu, 2015; Lehtinen et al., 2014). At the same time, this practice can favor plant growth and, by acting as a key source of soil organic matter, influence various soil physical, chemical, and biological properties (Powlson et al., 2008; Osborne et al., 2014).

Despite the plethora of studies related to these conservation management practices, their ability to reduce surface runoff and erosion have not been comprehensively compared against one another. Furthermore, it is not well understood if changes in surface runoff and erosion consistently correlate with changes in other soil physical, chemical, and biological indicators, or with cash crop yields. Recently, a global-scale soil health database (SoilHealthDB) was developed to integrate data related to conservation agriculture effects on soil health into a single open-source database (Jian et al., 2020b). This resource enables users to assess the benefits of conservation management on different soil-related processes and properties (Jian, Du, & Stewart, 2020a, 2020b; Jian et al., 2019; Stewart et al., 2018). Using SoilHealthDB, Jian, Du, Reiter, et al. (2020) developed a web-based calculator to quantify cover crop effects on soil health and cash crop productivity. However, due to data limitations, soil erosion and surface runoff were excluded from that analysis. Given the importance of erosion prevention for maintaining productive soils, and the lack of global-scale analyses analyzing effectiveness of different conservation agricultural practices toward this goal, we had the following study objectives: 1) quantify the effects of conservation management on surface runoff and soil erosion in croplands across the globe; and 2) evaluate interactions between changes in surface runoff and erosion and other soil health and agronomic indicators under conservation management. The results of this study provide insights for erosion prevention and soil health evaluation under conservation management.

2. Methods

We used data from SoilHealthDB (Jian et al., 2020b) to test the effect of conservation management on surface runoff and soil erosion. The initial version of SoilHealthDB (version1, commit number: 3f0e24d) had only limited data for surface runoff and soil erosion. Therefore, the first step of this study was to increase the number of observations related to these parameters in SoilHealthDB. We searched publications in ISI Web of Science, Google Scholar, and the China National Knowledge Infrastructure (CNKI), with the keywords “conservation management” and “soil erosion” or “runoff”. Only those publications that met quality control requirements (for specifics please refer to Jian et al., 2020b) were included. In total, data from 39 additional publications were compiled (Study numbers 282 to 321 in SoilHealthDB). These studies included 459 data points for soil erosion collected from 42 individual sites (a unique combination of longitude and latitude, same for the runoff sites), and 432 data points for surface runoff collected from 38 sites. Most of the data were collected from China, USA, Europe, and Africa (Fig. 1).

After digitizing and compiling the soil erosion and surface runoff data, we used a log-transformation to calculate the response ratio, RR, as,

$$RR = \ln(x_{conservation}/x_{control}) \tag{1}$$

where $x_{conservation}$ represents soil erosion or surface runoff under conservation management, and $x_{control}$ represents soil erosion or surface runoff under non-conservation management control. Note that we used RR rather than the actual data reported because different papers used various timescales and units. However, within a specific paper, the timescale and unit for the control and treatment were always the same, allowing for the RR to capture variations specific to the tested conservation agriculture practice. Since the RR values did not follow normal distributions (Fig. 2a, b, 2d, 2e, and S1-S4), we used a non-parametric bootstrap resampling technique (Hesterberg, 2011) to sample from the RR distribution 10,000 times. We then used the mean and 95% confidence intervals to identify changes in surface runoff and soil erosion under conservation management.

Finally, based on the actual RR values, we analyzed whether changes in surface runoff and soil erosion under conservation management affected other soil physical, chemical, and biological properties and cash crop yield. Of the 40 possible indicators included in SoilHealthDB, we found that 18 parameters were measured at the same time as erosion, and 16 parameters were measured alongside surface runoff (Figure S5). Thirteen of those parameters had sufficient data (i.e., reported in >5% of studies) for us to analyze correlation with the ‘Spearman’ coefficient between these indicators and surface runoff and soil erosion (Figure S6). Those parameters were: cash crop yield (yield); bulk density (BD); soil organic carbon (SOC); soil nitrogen (N); soil phosphorus (P); soil potassium (K); aggregation and aggregate stability (aggregate); porosity; soil penetration resistance (penetration); soil infiltration rates (infiltration); subsurface nutrient leaching (leaching); soil temperature (ST); and soil water content (SWC).

3. Results

Conservation management practices reduced both soil erosion and surface runoff (Fig. 3). Surface runoff and soil erosion were significantly decreased under all different management practices (i.e., upper 95% confidence intervals < 0). Significant reductions in erosion and surface runoff were detected for all soil textures, with coarse- and medium-textured soils having greater reductions than fine-textured soils (Fig. 3). Use of CC and AF was associated with the greatest decreases in erosion compared to those measured under other conservation practices, with CC having significantly greater reductions compared to RR, RT, and NT, and AF having significantly

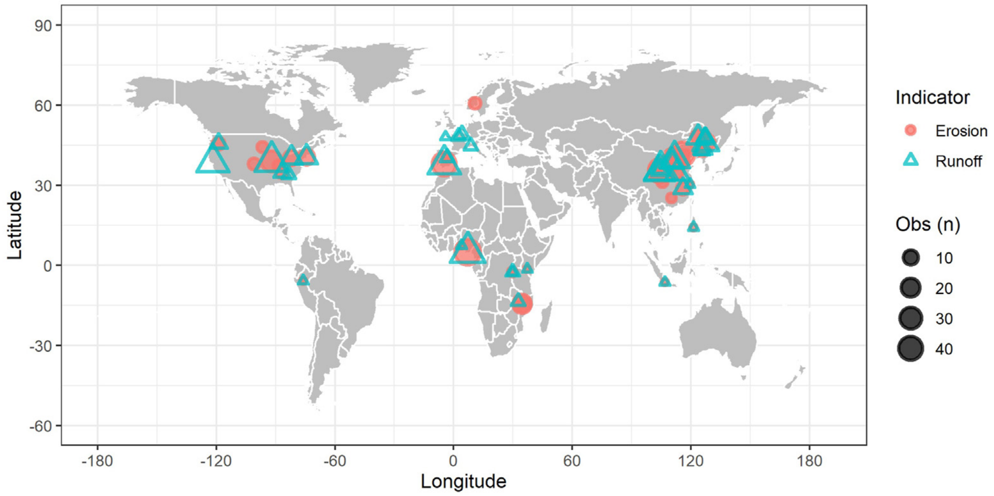


Fig. 1. The spatial distribution of sites compiled in the analysis, which included erosion data from 42 unique sites and runoff data from 38 unique sites (i.e., experimental locations with a unique combination of longitude and latitude). The size of the symbols refers to the number of observations in each site.

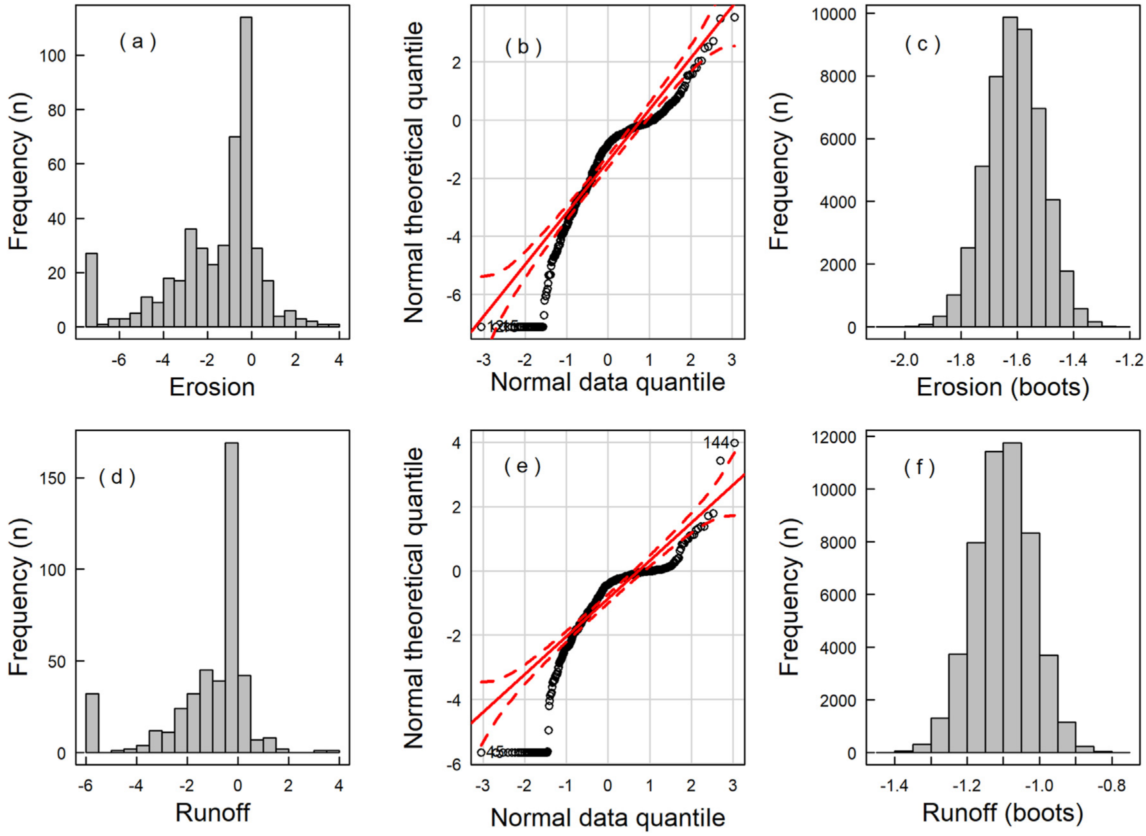


Fig. 2. Distribution of log-transformed erosion response ratios and runoff response ratios (panels a and d), normal quantile (panels b and e), and the distribution of response ratios after bootstrap resampling (panels c and f).

greater reductions than RR and NT. Of all practices, NT had the least change in erosion relative to controls. Changes in surface runoff followed a similar pattern, with CC causing significantly greater reductions than RR, NT, and AF, while RT reduced surface runoff significantly more than NT.

Soil erosion changes under conservation management showed significant correlations with some soil physical, chemical, and biological properties and with cash crop yield (Table 1). Soil erosion RR showed significant negative relationships with RR of yield, SOC, and porosity ($r < -0.3$ and $p < 0.05$), indicating that reduced erosion under conservation management was associated with higher values for those parameters. In contrast, a positive relationship was detected between RR of erosion, BD, and leaching, indicate that reduced soil erosion under conservation management can help to decrease soil BD and nutrient leaching ($r > 0.3$ and $p < 0.05$). For the other indicators (i.e., infiltration, N, P, K, penetration, ST, and SWC), we did not detect significant relationships with soil erosion ($p \geq 0.05$) Table 1 and

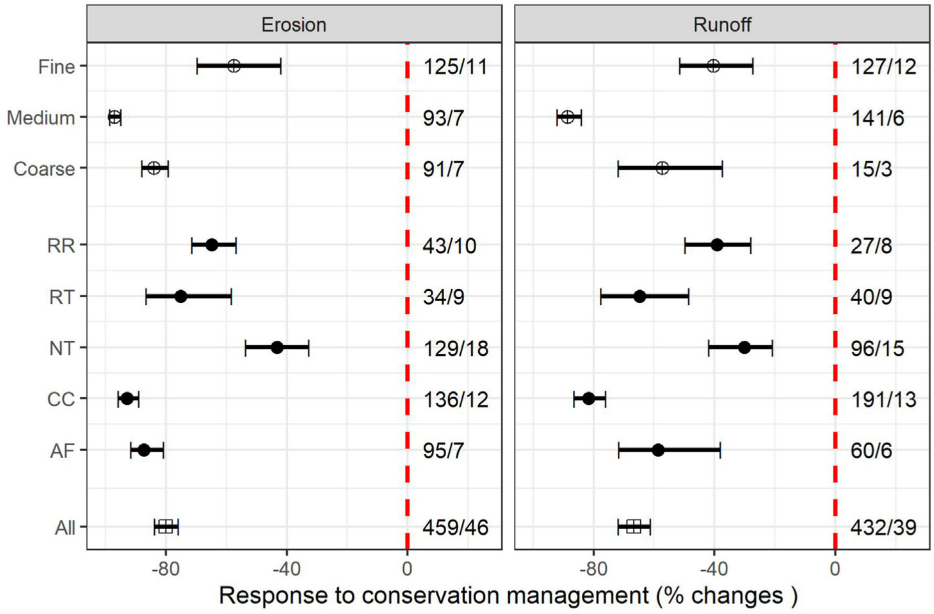


Fig. 3. Bootstrap resampling results of change in soil erosion (left panel) and surface runoff (right panel) due to implementation of agroforestry (AF), cover crop (CC), no-till (NT), reduced tillage (RT), and residue return (RR). Changes of erosion and runoff were also grouped by soil texture (coarse, medium, and fine). Note that the response ratios (RR; Equation (1)) are presented as percent change, calculated as 100 × [exp(RR)-1]. Dots and squares represent the mean values of bootstrap resampling results, and the bars are 95% confidence intervals. The numbers after each bar represent number of observations obtained from number of studies, e.g., there are in total 459 soil erosion observations obtained from 46 studies.

Table 1
Spearman correlations between response ratios (RR) of soil erosion and surface runoff and 13 other soil health indicators. Acronyms: BD = bulk density; SOC = soil organic carbon; N = soil nitrogen; P = soil phosphorus; K = soil potassium; ST = soil temperature; SWC = soil water content.

Indicator	r (Spearman)	p (Spearman)	Sample (n)	Study (n)
Soil erosion				
Yield	−0.43	<0.01	67	13
BD	0.24	<0.05	71	11
SOC	−0.36	<0.01	52	13
N	−0.03	0.864	30	7
P	0.16	0.502	20	4
K	0.17	0.468	21	5
Aggregation	−0.07	0.710	28	8
Porosity	−0.58	<0.01	21	4
Penetration	−0.31	0.331	12	3
Infiltration	0.002	0.994	14	2
Leaching	0.80	<0.01	121	9
ST	−0.38	0.144	16	2
SWC	−0.05	0.630	102	11
Surface runoff				
Yield	−0.37	<0.05	52	11
BD	−0.11	0.400	62	9
SOC	−0.18	0.234	44	9
N	−0.10	0.567	36	7
P	0.26	0.281	19	3
K	0.22	0.363	19	3
Aggregation	−0.39	0.067	23	7
Porosity	−0.49	<0.05	21	4
Penetration	−0.11	0.703	14	4
Infiltration	−0.55	<0.05	14	2
Leaching	0.75	<0.01	122	9
ST	−0.36	0.191	15	1
SWC	0.18	0.080	96	9

Figure S6).

We found that RR of yield, porosity, and infiltration showed significant negative correlations ($r < 0.3$ and $p < 0.05$) with surface runoff RR, indicating that decreased runoff by conservation management can improve soil porosity and soil infiltration rate. On the other hand, leaching was positively related with runoff ($r > 0.3$ and $p < 0.05$), indicating that reduced runoff under conservation management can also reduce soil nutrient leaching. We found no significant relationships between surface runoff and BD, SOC, soil N, P, K, aggregation, soil penetration, soil temperature, and soil water content ($p > 0.05$; Table 1 and Figure S7).

4. Discussion

4.1. *Runoff and erosion dynamics under conservation management*

Conservation management is a term that encompasses a broad suite of practices aimed at fostering sustainable agricultural production. While many individual studies and larger analyses have analyzed different aspects of conservation management, the ability of different practices to affect surface runoff and soil erosion has not previously been compared at global scales. In this study, we addressed this gap by collecting 432 surface runoff comparisons from 39 studies and 459 soil erosion comparisons from 46 studies. We then analyzed five different types of conservation management practices – agroforestry (AF), cover cropping (CC), reduced tillage (RT), no-till (NT), and residue return (RR) – along with the relationships between changes in surface runoff and erosion and 13 soil health and agronomic indicators. All studied management practices were found to decrease surface runoff and erosion, thus showing that observations from individual studies (Bekele-Tesemma, 1997; Cooper et al., 1996; König, 1992; Kusumandari & Mitchell, 1997; Lal, 1989; Reganold et al., 1993) apply at larger scales. More generally, results in this study showed that surface runoff decreased by 67% and soil erosion decreased by 80% compared to amounts measured under comparable controls.

Among different practices, CC was associated with the greatest reductions in both surface runoff and erosion (Fig. 3). There are several mechanisms associated with CC that can explain these results. Use of CC can help to decrease the area and duration of exposed soil (Morgan, 2009), and can increase soil aggregate size distributions (Blanco-Canqui et al., 2013), soil porosity (Repullo-Ruibérriz et al., 2018), surface roughness (Morgan, 2009), and SOC (Jian, Du, Reiter, et al., 2020). Therefore, the study results suggest that CC is one of the most effective means of reducing surface runoff and erosion, and for this reason should continue to warrant consideration as part of crop rotations.

Agroforestry (AF) caused similar decreases in soil erosion as CC, though the reductions in surface runoff associated with AF were significantly less than under CC. These results suggest that having perennial tree cover may be effective in reducing the erosive power of rainfall, even as surface runoff changes vary more based on differences in plant species, growth characteristics, and spacing (Cooper et al., 1996; König, 1992; Kusumandari & Mitchell, 1997; Reganold et al., 1993; Shi et al., 2018; Yong, 1989). Certain tree types, including various oak and conifer species, can also impart hydrophobic compounds onto the soil, thereby influencing infiltration rates and surface runoff (Chen, Pangle, et al., 2020; Doerr et al., 2006; Ebel et al., 2012; Ebel & Moody, 2017; Imeson et al., 1992; Tessler et al., 2008). While often associated with wildfires and severe droughts, water repellency can also develop in undisturbed forests (Di Prima et al., 2017; Doerr et al., 2000), including in relatively humid regions (Chen, McGuire, & Stewart, 2020).

Somewhat surprisingly, RT was associated with significantly greater reductions in surface runoff and erosion than NT. These results may reflect differences in systems where these practices are typically implemented. For example, many intensively cultivated crops (e.g., vegetables, tobacco) can conducive to RT more than NT, so RT may be better aimed at reducing the severe levels of disturbance associated with conventional practices in these systems (Hazel et al., 2008; Willekens et al., 2014). Likewise, RT practices may be more effective than NT at preventing or alleviating problems with compaction in cropping systems such as cotton (McClanahan, 2019; Schwab et al., 2002). Ridge tillage, a type of RT that aims to reduce slope length, is commonly implemented in highly erodible and other marginal croplands where its effectiveness may be particularly pronounced (Zhang et al., 2004). Conversely, NT is often used in row cropping systems that already have high productivity and, potentially, less severe erosion issues (Dıaz-Zorita et al., 2002; Thomas et al., 2007), thus reducing its potential to alter surface runoff and erosion.

All soil textures showed significant reductions in runoff and erosion when managed using conservation practices, though coarse- and medium-textured soils had significantly greater reductions than fine-textured ones. Soil particle size is an important factor influencing the detachment and transport processes (Rienzi et al., 2013), with silt-sized particles often representing the most easily dispersed (Miller & Baharuddin, 1987; Wang et al., 2014). The physical protection for the soil surface offered by some conservation management practices (e.g., NT, CC, RR) may be particular important for the medium-textured soils with high silt contents. Likewise, coarse soils typically have increased particle size and therefore may benefit from decreases in runoff quantities and velocities (Biddoccu et al., 2016; Lal, 1989; Zhao et al., 2007; Zhu et al., 1989) that occur when conservation management practices are used. By contrast, fine-textured soils are often characterized by relatively low hydraulic conductivities and infiltrability, so increases in infiltration rates linked to conservation management practices (Jian, Du, Reiter, et al., 2020) may not sufficiently reduce surface runoff to prevent erosion from occurring. Fine-textured soils can also be more problematic to manage, and may suffer from intended issues such as compaction and water-logging (Chen & Weil, 2011) when conservation practices are implemented under non-ideal conditions.

4.2. Runoff and erosion reduction correlated to other soil health indicators

Using Spearman correlation, we analyzed the relationships between changes in runoff and erosion and other 13 soil health and productivity indicators (Table 1). Yield, SOC, porosity, and aggregation were negatively correlated with surface runoff or soil erosion changes under conservation management (Fig. 4). Increased soil porosity can provide additional storage for rainfall, thus reducing surface runoff and soil erosion. Enhanced SOC can improve soil aggregation and retain more nutrient elements in the soil (Kaye & Quemada, 2017), which can lead to better cash crop yields (Kabir & Koide, 2000; Sainju et al., 2003; Zhang et al., 2012). Indeed, our results showed that cash crop yield had a significant negative relationship with soil erosion, consistent with previous studies (Yoo et al., 1988; Banda et al., 1994). However, the relationship between yield and surface runoff changes was not significant in our study. One possible reason for this discrepancy is that this study only included 52 observations, from 11 individual sites, that quantified both yield and surface runoff. Among those observations were field experiments that showed both increased yield (Langdale et al., 1992) and decreased yield (Marques et al., 2010) under conservation management practices. More work may therefore be needed to understand if yield is affected by changes in surface runoff quantity.

Leaching was positively correlated with runoff and erosion changes, which is consistent with findings from individual sites (Olson et al., 2014) and more comprehensive meta-analyses (Jian et al., 2020a). Other studies have found including CCs during fallow seasons can lead to plants rooting deeper in the soil profile, which can increase soil macropores and SOC and thereby act to reduce surface runoff, soil erosion, and BD (Stavi et al., 2012).

Neither surface runoff nor erosion showed significant correlations with soil N, P, K, penetration resistance, ST and SWC (Table 1), even though some of these parameters are closely related to other indicators that had significant responses. For example, SOC often increases soil nutrient retention, yet the overall macro-nutrient concentrations did not change. One reason for this result could be that many of the experiments provided ample fertilization, thus masking any differences in nutrient availability or holding capacity caused by the different practices. However, conservation management practices were also associated with lower nutrient leaching, thus showing a potential benefit even if fertilization practices do not vary with conservation management. Likewise, soil water content was not significantly correlated with changes in runoff and erosion, even though porosity and infiltration rates both showed significant increases in response. Many studies only measure soil water content once or a few times per study, which may not be sufficient to detect changes in water availability over the whole growing season. Several recent meta-analyses have also called into question the common assumption that increases in soil organic matter translates to increased plant available water (Jian et al., 2020a; Minasny et al., 2017), meaning that more study may be needed to untangle these interactions. At the same time, other soil health indicators (e.g., weed and disease control) lacked sufficient observations to perform any analysis (Fig. 4). Continuing to compile new data into SoilHealthDB may make it possible to test such indicators in future analyses.

4.3. Limitations and perspective

In this study we only collected measurements of erosion caused by surface runoff; however, wind erosion is another serious

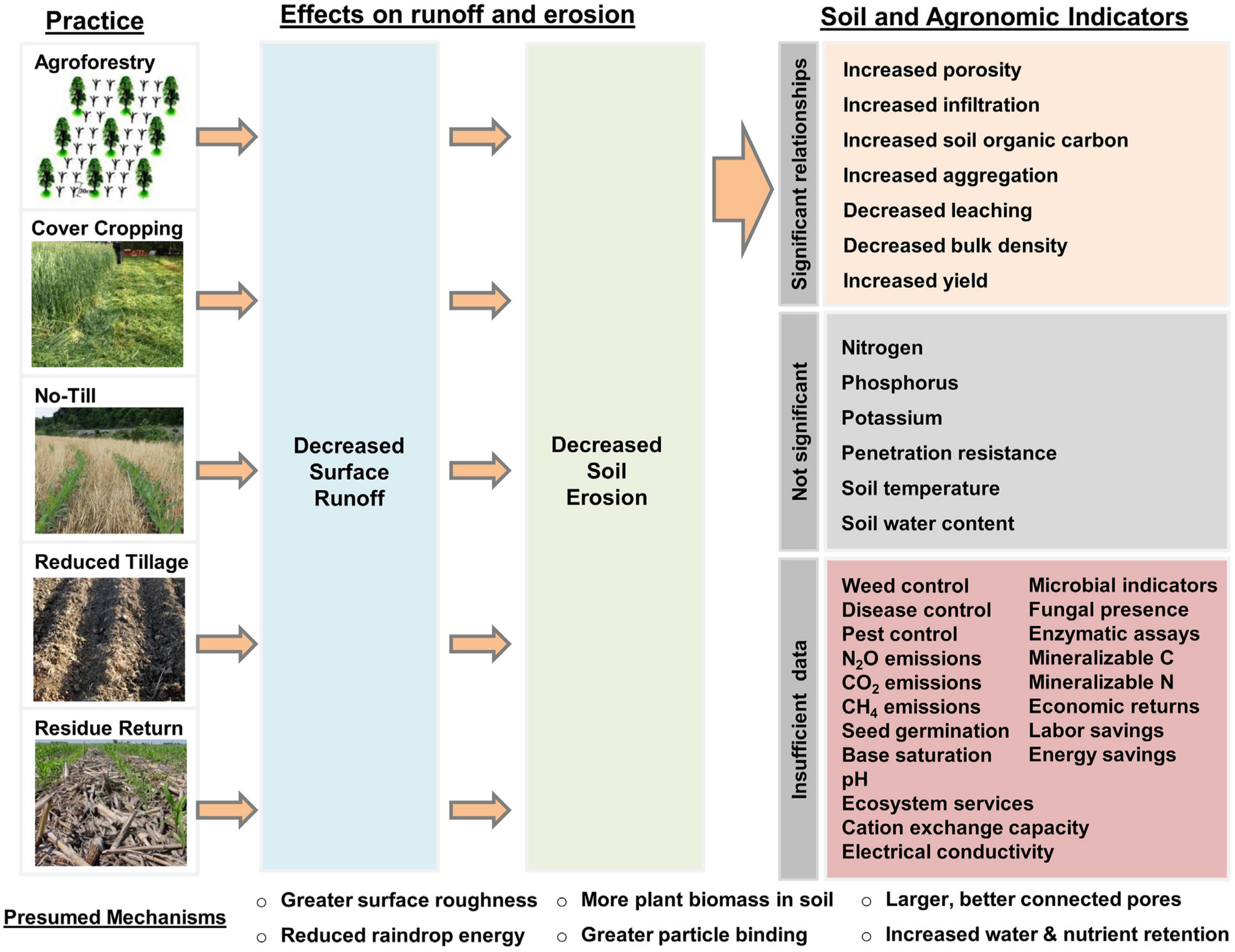


Fig. 4. Conservation management methods analyzed in this study led to significant decreases in surface runoff, which likely decreased soil erosion. These changes were significantly correlated with certain soil and agronomic indicators (upper right) and not correlated with others (middle right), with other indicators lacking sufficient data (lower right). Bullet points at the bottom indicate presumed mechanisms that may explain these dynamics.

environmental problem, particularly in arid regions (Zang, 2003). Here, conservation practice such as AF and CC may not be practical due to greater water requirements (Mitchell et al., 2017). There is promise that other practices, including NT, RT, and RR, can help control wind erosion in arid areas (Langdale et al., 1991; Leys & Heinjus, 1991; Liu, 2006; Zang, 2003). Future analyses may consider whether reductions in wind erosion resulting from these practices cause similar responses in other soil health indicators that were observed in our study.

Most sites in this study were located at mid-latitudes, with only a few sites from tropical and boreal regions (Fig. 1). It is therefore possible that our findings may not fully translate to cropping systems in non-temperate climates. Nonetheless, studies in tropical areas have shown that soil erosion under NT is lower than that from the conventional tillage (e.g., Merten & Minella, 2013), and that intercropping can prevent nutrient losses and soil erosion (e.g, Guimaraes et al., 2021). Both of these relationships are consistent with results from this study (Table 1 and Fig. 4). Other studies in boreal regions have indicated that cover crops can increase SOC and reduce soil erosion (e.g., Messiga et al., 2015; Theesfeld & Jelinek, 2017), consistent with our conclusion that SOC is negatively correlated with soil erosion (Table 1). Such examples indicate that, despite variations in crop types and other production-related aspects (e.g., length of growing seasons), the basic mechanisms by which conversation agriculture practices reduce soil degradation still apply across different climates.

We note that our study only considered runoff and soil erosion changes from individual practices (i.e., AF, CC, NT, RT, and RR), yet many agricultural producers use multiple strategies. We lacked data to analyze effects of combinations of strategies, but this may represent a future opportunity if enough primary data become available. As an example of possible synergies that exist between different practices, RT and NT can increase surface soil BD after transition from conventional tillage (Osunbitan et al., 2005), but CC may be useful for preventing this densification (Stirzaker & White, 1995; McClanahan, 2019). We therefore suggest that future studies should also consider interactions between multiple conservation management approaches.

5. Summary and conclusions

Soil erosion caused by surface runoff can affect soil physical, chemical, and biological properties and hinder cash crop yields. As a result, conservation management has been widely applied to combat soil erosion and make agriculture more sustainable. However, the effects of different conservation management strategies have not been evaluated at the global scale. In this study, we collected data from studies that compared conservation management practices with controls, focusing on five practices: agroforestry, cover cropping, reduced tillage, no-till, and residue return. We then analyzed the relationships between soil erosion and runoff and 13 other soil health indicators (i.e., yield, bulk density, soil organic carbon, soil nitrogen, phosphorus, potassium, aggregation, porosity, penetration resistance, infiltration, soil nutrient leaching, soil temperature, and soil water content). The results showed that conservation management practices significantly decreased soil erosion, with a mean decrease of 80% (95% confidence intervals from 33% to 98%). Similarly, surface runoff was reduced by an overall average of 67% (95% confidence intervals from 21% to 92%). Decreased soil erosion and runoff likely contributed to increase cash crop yield, soil organic carbon, aggregation, and infiltration.

Of the five studied conservation agriculture practices, cover cropping provided the greatest reductions in soil erosion, followed by agroforestry. Cover cropping also provided the greatest reductions in surface runoff, emphasizing that continuous vegetative covers can prevent erosive forces from disturbing soil surfaces. In contrast, no-till was determined to be the least useful practice for reducing surface runoff and soil erosion, even when compared to reduced tillage strategies. While more work is needed to evaluate and compare combinations of practices (e.g., no-till combined with cover crops), it may be useful to consider these relative differences in effectiveness when incentivizing and implementing conservation agriculture at larger scales.

Altogether, this study highlighted the importance of conservation management in improving soil health properties in croplands via reductions in surface runoff and erosion. Maintenance of soil health is becoming ever more important as the global population increases and becomes more affluent. In addition, a systematic analysis of soil erosion and runoff under conservation management substantially improved the coverage of the global soil health database, SoilHealthDB. Therefore, the results from this study can be used to further improve soil health analyses by including soil erosion and runoff indicators in future assessments.

Data and code availability

All the data and code to support and reproduce the results of this analysis can be found at: github.com/jinshijian/SoilHealthErosion.

Author contributions

Xuan Du and Jinshi Jian conceived this study and designed the primary analysis. Xuan Du collected an additional data required in this study and compiled those data into the SoilHealthDB. Jinshi Jian analyzed the data and generated all the figures. Can Du and Ryan Stewart provided feedbacks and insights in all phases. Xuan Du and Jinshi Jian wrote the manuscript in close collaboration with all authors.

Declaration of competing interest

The authors declare no conflict of interest.

Acknowledgments

Xuan Du was supported by the conservation management and soil erosion project funded by the Yangling Vocational & Technical College, grant number: A2019009. Jinshi Jian was supported by the Strategic Priority Research Program of Chinese Academy of Sciences, under contract number XDA20040202 and the US Department of Energy, Office of Science, Biological and Environmental Research as part of the Terrestrial Ecosystem Sciences Program, under contract DE-AC05-76RL01830. Can Du was supported by the Yangling Vocational & Technical College 2019 Natural Science Research Fund Project, under grant number: A2019048. Ryan Stewart was supported by the U.S. Department of Agriculture NRCS Conservation Innovation Grant (No. 69-3A75-14-260) and the Virginia Agricultural Experiment Station and the Hatch Program of the National Institute of Food and Agriculture, U.S. Department of Agriculture.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.iswcr.2021.08.001.

References

Banda, A. Z., Maghembe, J. A., Ngugi, D. N., & Chome, V. A. (1994). Effect of intercropping maize and closely spaced Leucaena hedgerows on soil conservation and maize yield on a steep slope at Ntcheu, Malawi. *Agroforestry Systems, 27*(1), 17–22. https://doi.org/10.1007/BF00704831

Bekele-Tesemma, A. (1997). *A participatory agroforestry Approach for Soil and water Conservation in Ethiopia.*. Doctoral dissertation. Wageningen University and Research.

Berhe, A. A., Harte, J., Harden, J. W., & Torn, M. S. (2007). The significance of the erosion-induced terrestrial carbon sink. *BioScience, 57*(4), 337–346. https://doi.org/10.1641/B570408

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 and Tillage Research, 155*, 176–189. https://doi.org/10.1016/j.still.2015.07.005

Blanco-Canqui, H., Holman, J. D., Schlegel, A. J., Tatarko, J., & Shaver, T. M. (2013). Replacing fallow with cover crops in a semiarid soil: Effects on soil properties. *Soil Science Society of America Journal, 77*(3), 1026. https://doi.org/10.2136/sssaj2013.01.0006

Bridges, E. M., & Van Baren, J. H. V. (1997). Soil: An overlooked, undervalued and vital part of the human environment. *Environmentalist, 17*(1), 15–20.

Chen, J., McGuire, K. J., & Stewart, R. D. (2020b). Effect of soil water-repellent layer depth on post-wildfire hydrological processes. *Hydrological Processes, 34*(2), 270–283. https://doi.org/10.1002/hyp.13583

Chen, J., Pangle, L. A., Gannon, J. P., & Stewart, R. D. (2020a). Soil water repellency after wildfires in the blue ridge mountains, United States. *International Journal of Wildland Fire, 29*(11), 1009–1020. https://doi.org/10.1071/WF20055

Chen, G., & Weil, R. R. (2011). Root growth and yield of maize as affected by soil compaction and cover crops. *Soil and Tillage Research, 117*, 17–27. https://doi.org/10.1016/j.still.2011.08.001

Cooper, P. J. M., Leakey, R. R., Rao, M. R., & Reynolds, L. (1996). Agroforestry and the mitigation of land degradation in the humid and sub-humid tropics of Africa. *Experimental Agriculture, 32*(3), 235–290. https://doi.org/10.1017/S0014479700026223

Deng, C., Chen, Z., & Chen, Z. (2019). Intensity evaluation and spatial distribution characteristics of soil erosion in red soil region in south China. *Journal of Fujian Normal University (Philosophy and Social Sciences Edition), 35*(3), 88–95.

Di Prima, S., Bagarello, V., Angulo-Jaramillo, R., Bautista, I., Cerdà, A., Del Campo, A., González-Sanchis, M., Iovino, M., Lassabatere, L., & Maetzke, F. (2017). Impacts of thinning of a Mediterranean oak forest on soil properties influencing water infiltration. *Journal of Hydrology and Hydromechanics, 65*(3), 276–286. http://hdl.handle.net/10251/104723.

Doerr, S. H., Shakesby, R. A., Blake, W. H., Chafer, C. J., Humphreys, G. S., & Wallbrink, P. J. (2006). Effects of differing wildfire severities on soil wettability and implications for hydrological response. *Journal of Hydrology, 319*(1–4), 295–311. https://doi.org/10.1016/j.jhydrol.2005.06.038

Doerr, S. H., Shakesby, R. A., & Walsh, R. (2000). Soil water repellency: Its causes, characteristics and hydro-geomorphological significance. *Earth-Science Reviews, 51*(1–4), 33–65. https://doi.org/10.1016/S0012-8252(00)00011-8

Diaz-Zorita, M., Duarte, G. A., & Grove, J. H. (2002). A review of no-till systems and soil management for sustainable crop production in the subhumid and semiarid Pampas of Argentina. *Soil and Tillage Research, 65*(1), 1–18. https://doi.org/10.1016/S0167-1987(01)00274-4

Ebel, B. A., & Moody, J. A. (2017). Synthesis of soil-hydraulic properties and infiltration timescales in wildfire-affected soils. *Hydrological Processes, 31*(2), 324–340. https://doi.org/10.1002/hyp.10998

Ebel, B. A., Moody, J. A., & Martin, D. A. (2012). Hydrologic conditions controlling runoff generation immediately after wildfire. *Water Resources Research, 48*(3). https://doi.org/10.1029/2011WR011470

Fu, Q., Luo, Y., & Chai, X. (1995). Ecological effects and economic bencfit of the complex agro-forestry systems in low-hilland red soil areas. *Chinese Journal of Ecology, 14*(6), 11–15.

Galang, M. A., Markewitz, D., Morris, L. A., & Bussell, P. (2007). Land use change and gully erosion in the Piedmont region of South Carolina. *Journal of Soil and Water*

Conservation, 62(3), 122–129.

García-Ruiz, J. M., Beguería, S., Nadal-Romero, E., González-Hidalgo, J. C., Lana-Renault, N., & Sanjuán, Y. (2015). A meta-analysis of soil erosion rates across the world. *Geomorphology, 239*, 160–173. https://doi.org/10.1016/j.geomorph.2015.03.008

Guimarães, D. V., Silva, M. L. N., Beniaich, A., Pio, A., Gonzaga, M. I. S., Avanzi, J. C., Bispo, D. F. A., & Curi, N. (2021). Dynamics and losses of soil organic matter and nutrients by water erosion in cover crop management systems in olive groves, in tropical regions. *Soil and Tillage Research, 209*, Article 104863. https://doi.org/10.1016/j.still.2020.104863

Harwood, R. R. (1990). A history of sustainable agriculture. In C. A. Edwards (Ed.), *Sustainable agricultural systems*. Ankeny, IA, USA: Soil and Water Conservation Society.

Hazel, D. W., Franklin, E. C., Thomas, K. T., & Jennings, G. D. (2008). Integrated practices for reducing sediment loss from Piedmont tobacco fields. *Journal of Soil and Water Conservation, 63*(3), 143–152. https://doi.org/10.2489/jswc.63.3.143

Hesterberg, T. (2011). Bootstrap. *Wiley Interdisciplinary Reviews: Computational Statistics, 3*(6), 497–526.

Imeson, A. C., Verstraten, J. M., Mulligen, Van, J, E., & Sevink, J. (1992). The effects of fire and water repellency on infiltration and runoff under Mediterranean type forest. *Catena, 19*(3–4), 345–361. https://doi.org/10.1016/0341-8162(92)90008-Y

Jian, J., Du, X., Reiter, M. S., & Stewart, R. D. (2020). A meta-analysis of global cropland soil carbon changes due to cover cropping. *Soil Biology and Biochemistry, 143*, Article 107735. https://doi.org/10.1016/j.soilbio.2020.107735

Jian, J., Du, X., & Stewart, R. (2020a). A calculator to quantify cover crop effects on soil health and productivity. *Soil and Tillage Research, 199*, Article 104575. https://doi.org/10.1016/j.still.2020.104575

Jian, J., Du, X., & Stewart, R. (2020b). A database for global soil health assessment. *Scientific Data, 7*(16). https://doi.org/10.1038/s41597-020-0356-3

Jian, J., Stewart, R., & Du, X. (2019). SoilHealthDB. *Figshare*. https://doi.org/10.6084/m9.figshare.8292176.v8

Kabir, Z., & Koide, R. T. (2000). The effects of dandelion or a cover crop onmycorrhizal inoculum potential, soil aggregation and yield of maize. *Agriculture, Ecosystems & Environment, 78*, 167–174. https://doi.org/10.1016/S0167-8809(99)00121-8

Karlen, D. L., Kovar, J. L., Cambardella, C. A., & Colvin, T. S. (2013). Thirty-year tillage effects on crop yield and soil fertility indicators. *Soil and Tillage Research, 130*, 24–41. https://doi.org/10.1016/j.still.2013.02.003

Kaye, J. P., & Quemada, M. (2017). Using cover crops to mitigate and adapt to climate change. A review. *Agronomy for Sustainable Development, 37*(1). https://doi.org/10.1007/s13593-016-0410-x

König, D. (1992). The potential of agroforestry methods for erosion control in Rwanda. *Soil Technology, 5*(2), 167–176. https://doi.org/10.1016/0933-3630(92)90017-U

Kusumandari, A., & Mitchell, B. (1997). Soil erosion and sediment yield in forest agroforestry areas in West Java,Indonesia. *Journal of Soil and Water Conservation, 52*(5), 376–380.

Lal, R. (1989a). Agroforestry systems and soil surface management of a tropical alfisol.II: Water runoff, soil-erosion, and nutrient loss. *Agroforestry Systems, 8*(2), 97–111. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?db=pubmed&cmd=Retrieve&dopt=AbstractPlus&list_uids=A1989AE99700001.

Lal, R. (1989b). Agroforestry systems and soil surface management of a tropical alfisol: - II: Water runoff, soil erosion, and nutrient loss. *Agroforestry Systems, 8*(2), 97–111. https://doi.org/10.1007/BF00123115

Langdale, G. W., Blevins, R. L., Karlen, D. L., Mccool, D. K., Nearing, M. A., Skidmore, E. L., Thomas, A. W., Tyler, D. D., & Williams, J. R. (1991). Cover crop effects on soil erosion by wind and water. *Cover Crops for Clean Water*, 15–22.

Langdale, G. W., West, L. T., Bruce, R. R., Miller, W. P., & Thomas, A. W. (1992). Restoration of eroded soil with conservation tillage. *Soil Technology, 5*(1), 81–90. https://doi.org/10.1016/0933-3630(92)90009-P

Lehtinen, T., Schlatter, N., Baumgarten, A., Bechini, L., Krüger, J., Grignani, C., Zavattaro, L., Costamagna, C., & Spiegel, H. (2014). Effect of crop residue incorporation on soil organic carbon and greenhouse gas emissions in European agricultural soils. *Soil Use & Management, 30*(4), 524–538. https://doi.org/10.1111/sum.12151

Leys, J. F., & Heinjus, D. (1991). Simulated wind erosion in the south Australian murray mallee. *Conservation Service of NSW*.

Liu, H. (2006). *An experimental study of anti-wind erosion capacity of conservation farming system in the northern foot of Yinshan Moutain.*. Doctoral dissertation. Inner Mongolia Agriculture University.

Lu, F. (2015). How can straw incorporation management impact on soil carbon storage? A meta-analysis. *Mitigation and Adaptation Strategies for Global Change, 20*(8), 1545–1568. https://doi.org/10.1007/s11027-014-9564-5

Marques, M. J., García-Muñoz, S., Muñoz-Organero, G., & Bienes, R. (2010). Soil conservation beneath grass cover in hillside vineyards under mediterranean climatic conditions (MADRID, Spain). *Land Degradation & Development, 21*(2), 122–131. https://doi.org/10.1002/ldr.915

McClanahan, S. J. (2019). *Evaluation of cover crops, conservation tillage, and nitrogen management in cotton production in southeastern Virginia.*. Doctoral dissertation. Virginia Tech.

Merten, G. H., & Minella, J. P. (2013). The expansion of Brazilian agriculture: Soil erosion scenarios. *International Soil and Water Conservation Research, 1*(3), 37–48. https://doi.org/10.1016/S2095-6339(15)30029-0

Messiga, A. J., Sharifi, M., Hammermeister, A., Gallant, K., Fuller, K., & Tango, M. (2015). Soil quality response to cover crops and amendments in a vineyard in Nova Scotia, Canada. *Scientia Horticulturae, 188*, 6–14. https://doi.org/10.1016/j.scienta.2015.02.041

Meyer, L. D., Dabney, S. M., Murphree, C. E., Harmon, W. C., & Grissinger, E. H. (1997). Effect of cropland management practices on storm runoff and erosion. Proceedings of the conference on management of landscapes distributed by channel incision. *The University of Mississippi, Oxford Campus, Mississippi*, 983–989.

Miller, W. P., & Baharuddin, M. K. (1987). Particle size of interrill-eroded sediments from highly weathered soils. *Soil Science Society of America Journal, 51*(6), 1610–1615. https://doi.org/10.2136/sssaj1987.03615995005100060037x

Minasny, B., Malone, B. P., McBratney, A. B., Angers, D. A., Arrouays, D., Chambers, A., Chaplot, V., Chen, Z. S., Cheng, K., Das, B. S., Field, D. J., Gimona, A., Hedley, C. B., Hong, S. Y., Mandal, B., Marchant, B. P., Martin, M., McConkey, B. G., Mulder, V. L., … Winowiecki, L. (2017). Soil carbon 4 per mille. *Geoderma, 292*, 59–86. https://doi.org/10.1016/j.geoderma.2017.01.002

Mitchell, J. P., Shrestha, A., Mathesius, K., Scow, K. M., Southard, R. J., Haney, R. L., Schmidt, R., Munk, D. S., & Horwath, W. R. (2017). Cover cropping and no-tillage improve soil health in an arid irrigated cropping system in California's San Joaquin Valley, USA. *Soil and Tillage Research, 165*, 325–335. https://doi.org/10.1016/j.still.2016.09.001

Morgan, R. P. C. (2009). *Soil erosion and conservation*. Malden, MA, USA: John Wiley & Sons. Blackwell Publishing Company.

Olson, K., Ebelhar, S. A., & Lang, J. M. (2014). Long-term effects of cover crops on crop yields, soil organic carbon stocks and sequestration. *Open Journal of Soil Science, 4*(8), 284–292. https://doi.org/10.4236/ojss.2014.48030

Osborne, S. L., Johnson, J. M. F., Jin, V. L., Hammerbeck, A. L., Varvel, G. E., & Schumacher, T. E. (2014). The impact of corn residue removal on soil aggregates and particulate organic matter. *Bioenergy Research, 7*(2), 559–567. https://doi.org/10.1007/s12155-014-9413-0

Osunbitan, J. A., Oyedele, D. J., & Adekalu, K. O. (2005). Tillage effects on bulk density, hydraulic conductivity and strength of a loamy sand soil in southwestern Nigeria. *Soil and Tillage Research, 82*(1), 57–64. https://doi.org/10.1016/j.still.2004.05.007

Powlson, D. S., Riche, A. B., Coleman, K., Glendining, M. J., & Whitmore, A. P. (2008). Carbon sequestration in European soils through straw incorporation: Limitations and alternatives. *Waste Management, 28*(4), 741–746. https://doi.org/10.1016/j.wasman.2007.09.024

Puget, P., & Lal, R. (2005). Soil organic carbon and nitrogen in a Mollisol in central Ohio as affected by tillage and land use. *Soil and Tillage Research, 80*(1–2), 201–213. https://doi.org/10.1016/j.still.2004.03.018

Ran, L., Lu, X., & Xu, J. (2013). Effects of vegetation restoration on soil conservation and sediment loads in China: A critical review. *Critical Reviews in Environmental Science and Technology, 43*(13), 1384–1415. https://doi.org/10.1080/10643389.2011.644225

Reganold, J. P., Palmer, A. S., Lockhart, J. C., & Macgregor, A. N. (1993). Soil quality and financial performance of biodynamic and conventional farms in New Zealand. *Science, 260*(5106), 344–349. https://doi.org/10.1126/science.260.5106.344

Repullo-Ruibérriz de Torres, M. A., Ordóñez-Fernández, R., Giráldez, J. V., Márquez-García, J., Laguna, A., & Carbonell-Bojollo, R. (2018). Efficiency of four different seeded plants and native vegetation as cover crops in the control of soil and carbon losses by water erosion in olive orchards. *Land Degradation & Development, 29*(8), 2278–2290. https://doi.org/10.1002/ldr.3023

Rienzi, E. A., Fox, J. F., Grove, J. H., & Matocha, C. J. (2013). Interrill erosion in soils with different land uses: The kinetic energy wetting effect on temporal particle size distribution. *Catena, 107*, 130–138. https://doi.org/10.1016/j.catena.2013.02.007

Sainju, U., Singh, B., & Whitehead, W. (2002). Long-term effects of tillage, cover crops, and nitrogen fertilization on organic carbon and nitrogen concentrations in sandy loam soils in Georgia, USA. *Soil and Tillage Research, 63*(3–4), 167–179. https://doi.org/10.1016/S0167-1987(01)00244-6

Sainju, U. M., Whitehead, W. F., & Singh, B. P. (2003). Cover crops and nitrogen fertilization effects on soil aggregation and carbon and nitrogen pools. *Canadian Journal of Soil Science, 83*(2), 155–165. https://doi.org/10.4141/S02-056

Schubert, S. D., Suarez, M. J., Pegion, P. J., Koster, R. D., & Bacmeister, J. T. (2004). On the cause of the 1930s Dust Bowl. *Science, 303*(5665), 1855–1859. https://doi.org/10.1126/science.1095048

Schwab, E. B., Reeves, D. W., Burmester, C. H., & Raper, R. L. (2002). Conservation tillage systems for cotton in the Tennessee Valley. *Soil Science Society of America Journal, 66*(2), 569–577.

Shi, L., Feng, W., Xu, J., & Kuzyakov, Y. (2018). Agroforestry systems: Meta-analysis of soil carbon stocks, sequestration processes, and future potentials. *Land Degradation & Development*. https://doi.org/10.1002/ldr.3136. August.

Stavi, I., Lal, R., Jones, S., & Reeder, R. C. (2012). Implications of cover crops for soil quality and geodiversity in a humid-temperate region in the midwestern USA. *Land Degradation & Development, 23*(4), 322–330. https://doi.org/10.1002/ldr.2148

Stewart, R. D., Jian, J., Gyawali, A. J., Thomason, W. E., Badgley, B. D., Reiter, M. S., & Strickland, M. S. (2018). What we talk about when we talk about soil health. *Agricultural & Environmental Letters*, 5–9. https://doi.org/10.2134/ael2018.06.0033

Stirzaker, R. J., & White, I. (1995). Amelioration of soil compaction by a cover-crop for no-tillage lettuce production. *Australian Journal of Agricultural Research,* *46*(3), 553–568. https://doi.org/10.1071/AR9950553

Stott, D. E., & Moebius-Clune, B. N. (2017). Soil health: Challenges and opportunities. In *Global soil security* (pp. 109–121). Springer.

Terra, J. A., Reeves, D. W., Shaw, J. N., & Raper, R. L. (2005). Impacts of landscape attributes on carbon sequestration during the transition from conventional to conservation management practices on a Coastal Plain field. *Journal of Soil and Water Conservation, 60*(6), 438–446. http://www.jswconline.org/content/60/6/438.

Tessler, N., Wittenberg, L., Malkinson, D., & Greenbaum, N. (2008). Fire effects and short-term changes in soil water repellency–Mt. Carmel, Israel. *Catena, 74*(3), 185–191. https://doi.org/10.1016/j.catena.2008.03.002

Theesfeld, I., & Jelinek, L. (2017). A misfit in policy to protect Russia's black soil region. An institutional analytical lens applied to the ban on burning of crop residues. *Land Use Policy, 67*, 517–526. https://doi.org/10.1016/j.landusepol.2017.06.018

Thomas, G. A., Titmarsh, G. W., Freebairn, D. M., & Radford, B. J. (2007). No-tillage and conservation farming practices in grain growing areas of Queensland–a review of 40 years of development. *Australian Journal of Experimental Agriculture, 47*(8), 887–898. https://doi.org/10.1071/EA06204

Wang, J., & Li, Z. (2018). Research progress on water erosion in the black soil region of northereast China. *Journal of Agricultural and Resource Economics, 35*(5), 389–397. https://doi.org/10.13254/j.jare.2017.0328

Wang, L., Shi, Z. H., Wang, J., Fang, N. F., Wu, G. L., & Zhang, H. Y. (2014). Rainfall kinetic energy controlling erosion processes and sediment sorting on steep hillslopes: A case study of clay loam soil from the Loess plateau, China. *Journal of Hydrology, 512*, 168–176. https://doi.org/10.1016/j.jhydrol.2014.02.066

Willekens, K., Vandecasteele, B., Buchan, D., & De Neve, S. (2014). Soil quality is positively affected by reduced tillage and compost in an intensive vegetable cropping system. *Applied Soil Ecology, 82*, 61–71. https://doi.org/10.1016/j.apsoil.2014.05.009

Yong, A. (1989). *Agroforestry for soil conservation*. Exeter: International BPCC Wheatons Ltd.

Yoo, K. H., Touchton, J. T., & Walker, R. H. (1988). Runoff, sediment and nutrient losses from various tillage systems of cotton. *Soil and Tillage Research, 12*(2), 13–24. https://doi.org/10.1016/0167-1987(88)90052-9

Zang, Y. (2003). *Experimental study on soil wind erosion with conservation tillage treatment.*. Doctoral dissertation. China Agricultural University.

Zhang, J. H., Frielinghaus, M., Tian, G., & Lobb, D. A. (2004). Ridge and contour tillage effects on soil erosion from steep hillslopes in the Sichuan Basin, China. *Journal of Soil and Water Conservation, 59*(6), 277–284.

Zhang, X., Zhang, S., Chen, L., Liang, W., Li, Q., & Wei, K. (2012). Effects of conservation tillage on soil aggregation and aggregate binding agents in black soil of Northeast China. *Soil and Tillage Research, 124*, 196–202. https://doi.org/10.1016/j.still.2012.06.007

Zhao, J. F., Huang, G. B., Xin, P., Xie, K. Z., & Xu, A. X. (2007). Runoff and quantity of soil erosion under conservation tillage system by simulated rainfall. *Bulletin of Soil and Water Conservation, 27*(6), 16–19.

Zhao, G., Mu, X., Wen, Z., Wang, F., & Gao, P. (2013). Soil erosion, conservation, and eco-environment changes in the loess plateau of China. *Land Degradation & Development, 24*(5), 499–510. https://doi.org/10.1002/ldr.2246

Zhu, J. C., Gantzer, C. J., Anderson, S. H., Alberts, E. E., & Beuselinck, P. R. (1989). Runoff, soil, and dissolved nutrient losses from No-till soybean with winter cover crops. *Soil Science Society of America Journal, 53*(4), 1210. https://doi.org/10.2136/sssaj1989.03615995005300040037x