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Source: Canadian Journal of Soil Science, 102(3) : 659-671

Published By: Canadian Science Publishing

URL: https://doi.org/10.1139/cjss-2021-0080

Canadian Journal of
Soil Science

Article

Impact of conservation tillage on runoff, soil loss, and soil properties on acrisols and ferralsols in central Benin

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Abstract

The present study is aimed at assessing the impact of different tillage practices and mulch input rates on soil erosion and soil properties in Central Benin. The experiment was carried out at two sites (Dan and Za-zounmè) using a randomized complete block design. The effect of three tillage practices: contour ridging (CR), slope ridging (SR), and no-tillage (NT) and four mulch input rates (0, 3, 5, and 7 t·ha^{-1}) was investigated. The runoff, the soil, and nutrients losses were measured during the major rainy seasons of 2018 and 2019. Bulk density, gravimetric moisture, and water infiltration were collected in 2019. The effect of the interaction between tillage practices and mulch input rates was significant on runoff amount, runoff coefficient, soil loss, N, P, and K losses, and soil moisture. Over the investigated seasons, CR + 7M decreased runoff amount, runoff coefficient, soil loss, and N, P, and K losses by 100% compared to the treatments. NT was found to be effective in runoff and soil erosion controlling when combined with a mulch quantity greater than 3 t·ha^{-1}, and NT + 5M and NT + 7M reduced the soil loss, respectively, by more than 30% compared to the farmer's practice (SR + 0M) at both sites. Contour ridge treatments yielded more soil moisture than NT and slope ridge treatments. Whatever the tillage practice, the greatest gravimetric moisture was recorded on 5 and 7 t·ha^{-1} plots (i.e., CR + 7M, NT + 7M, and SR + 7M). This study provides decision makers with requisite information for effective soil erosion management in Benin where mechanization aids are limited.

Key words: conservation tillage, soil degradation, water erosion, Benin

Résumé

La présente étude vise à évaluer l'impact de différentes pratiques de travail du sol et de quantité de paillis sur l'érosion hydrique et les propriétés du sol au centre du Bénin. Elle a été menée sur deux sites (Dan et Za-zounmè) en utilisant un dispositif en bloc complet randomisé. L'effet de trois pratiques de travail du sol : le billonnage isohypse (CR), le billonnage suivant la pente (SR) et le sas-labour (NT) et quatre quantités de paillis (0, 3, 5 et 7 t .ha^{-1}) a été étudié. Le ruissellement, les pertes de terre et de nutriments ont été mesurés pendant la grande saison de pluies de 2018 et 2019. La densité apparente, l'humidité gravimétrique et l'infiltration d'eau ont été recueillies en 2019. L'effet de l'interaction entre les pratiques de travail du sol et les taux d'apport de paillis était significatif sur la quantité de ruissellement, le coefficient de ruissellement, la perte de sol, les pertes de N, P et K et l'humidité du sol. La combinaison CR + 7M a réduit la quantité de ruissellement, le coefficient de ruissellement, la perte de sol et les pertes de N, P et K de 100 % par rapport aux autres traitements. Le NT s'est avéré efficace pour contrôler le ruissellement et l'érosion du sol lorsqu'il était combiné à une quantité de paillis supérieure à 3 t.ha^{-1}, et le NT + 5M et le NT + 7M ont réduit la perte de sol de plus de 30 % par rapport à la pratique des agriculteurs (SR + 0M) sur les deux sites. Le CR a permis de conserver l'humidité du sol comparativement à SR. Quelle que soit la pratique de travail du sol, la plus grande humidité du sol a été enregistrée sur les parcelles ayant reçu 5 et 7 t.ha^{-1} (CR + 7M, NT + 7M et SR + 7M). Grâce à la présente étude, les décideurs disposeront des informations dont ils ont besoin pour gérer efficacement l'érosion du sol au Bénin où les moyens mécaniques sont restreints. [Traduit par la Rédaction]

Mots-clés : labour de conservation, dégradation du sol, érosion hydrique, Bénin

Introduction

Soil erosion constitutes to date one of the big challenges of low-income countries. The situation is more pronounced in Africa, resulting in soil degradation and declining crop yields. In the past decade, more than 45% of the total worldwide soil erosion occurred in Africa, where soil erosion degrades 5 to 6 million hectares annually and affects millions of people (FAO 2002; Assefa 2009). In Benin, water erosion has resulted in topsoil removal in many agroecological areas (Assogba et al. 2017). Barthès and Roose (2002) reported different sensitivity to rain erosivity across the country regions. In central Benin, water erosion is very recurrent due to the rain erosivity, non-sustainable agricultural practices (Igué et al. 2013), and geological composition dominated by the very impermeable rock of this peneplain landscape (Adam and Boko 1993). An average soil loss (SL) of 17.69 t·ha^{-1}·year^{-1} was reported at the Lokogba watershed in Aplahoué (Kouelo 2016). Changed agricultural practices are required to ensure the sustainability of agricultural systems as soil quality is one of the key factors determining agricultural productivity (Kumar et al. 2020) and food security.

A growing body of research over the past few years has shown that soil conservation practices can significantly curb water erosion along with the subsequent transport of nutrients and other pollutants (Lizotte et al. 2014; Doan et al. 2015). Conservation tillage and soil mulching are the most widely adopted soil conservation practices (Vincent-Caboud et al. 2019). Mulching plays a fundamental role in soil protection against erosion and soil moisture conservation (Mazarei and Ahangar 2013). Residue cover protects the soil against raindrops, limits surface runoff, increases soil organic matter (SOM) content, and creates conditions favourable for the creation of macropores that connect the topsoil with deeper part of soil profile (Araya et al. 2015; Toom et al. 2019). Appropriate tillage is considered as an important management tool to combat water erosion risks, to promote in situ water conservation, crop yield improvement, and stabilization in rainfed agricultural systems. However, tillage systems are site specific and depend on crop species (Sharma and Abrol 2005). Under certain soil, climate, and management conditions, the no-tillage (NT) land management may have potential advantages over the tillage. Reduction of runoff and erosion, increased soil organic carbon (SOC) content, increased root length and density, and soil water conservation are the main outcomes of NT practices (Lal 2004; Fiorini et al. 2018). NT practices are considered as Conservation Agriculture (CA) practices (FAO 2011). CA, including NT, requires increased knowledge of the system and adaptation to the site and farmer circumstances (Erenstein et al. 2012). The integration of CA into smallholder farming systems has to address the prevailing constraints without creating new complex ones (Thierfelde et al. 2013).

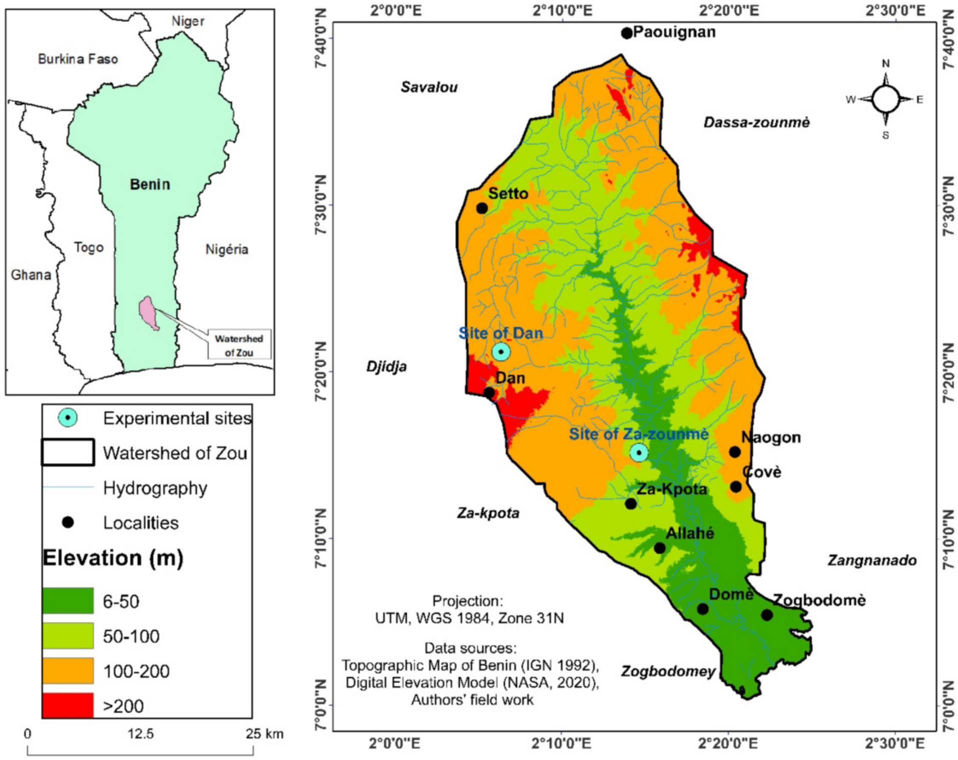
The feasibility of NT for smallholder farmers in Benin is constrained by biophysical, socio-economical, and technical challenges. Most farmers in Benin are not literate. That limits the adoption of new technologies (Akplo et al. 2019). Thus, the effect of reduced tillage is relatively unknown and little understood. Small traditional farmers are very conservative. They rely on approaches inherited from the past and firmly fixed in their traditional way of life. It is difficult to convince them to adopt new approaches. In addition, the effect of NT is long term. It is difficult for farmers who are not landowners (most farmers work on rented land) to invest in NT since they are not guaranteed to be on the same land for a long time. Providing more information about the effective soil erosion control practices in Benin is the most important stage for soil conservation. The global objective of the present study was to assess the impact of different tillage practices and mulch input rate on runoff, SL, and soil properties in Central Benin. Then, erosion plots were established under natural precipitation.

Materials and methods

Research area description

Two experimental sites were selected: Dan (07°21′35″ N; 02°05′09″ E) and Za-zounmè (07°12′50″ N; 02°15′40″ E) (Fig. 1). Both of them are situated on gently undulating denudation plateau (the slope inclination is 5% at Dan and 4.6% at Za-zounmè). Before implementing the experiences, both sites were fallowed since 2000 without any tillage. However, farmers frequently burned the natural vegetation that grows back when the rainy season resumes. Also, cattle from the area were grazing in the fields. The soil is Acrisol at Dan and Ferralsol at Za-zounmè (IUSS Working Group WRB 2015). A baseline soil fertility reference was collected along the diagonal of the field at a depth of 0–20 cm and analyzed at laboratory of soil analysis in Benin. At Dan, the soil is sandy–clay–loam, and the pH (water 1:2.5) is acid (5.63), organic matter content is 13.7 g·kg^{-1} of soil, exchangeable potassium content is 129.03 mg·kg^{-1} of soil, Bray P is 12.6 ppm, and total nitrogen content is 0.88 g·kg^{-1} of soil. Water infiltration rate is 41 cm·day^{-1}. At Za-zounmè, the soil texture is sandy–loam, the pH (water 1:2.5) is close to neutral (6.40), organic matter content is 12.4 g·kg^{-1} of soil, exchangeable potassium content is 140.76 mg·kg^{-1}, Bray P is 18.12 ppm, and total nitrogen content is 0.69 g·kg^{-1} of soil. Water infiltration rate is 120 cm·day^{-1}. The annual rainfall ranged between 1100 and 1300 mm for both sites. This agroecological zone is characterized by two cropping seasons: major (March to July) and minor (September to November) as a result of a bimodal rainfall regime. The average temperature recorded during the 2 years in the area was 27 °C. At Dan, the natural vegeta-

Fig. 1. Watershed of Zou and experimental field location. Projection: UTM WGS 1984 Zone 31 N. Data sources: Topographic Map of Benin (IGN 1992); Digital Elevation Map (NASA 2020); authors' fieldwork. [Colour online]



tion was dominated by guinea grass (*Panicum maximum* Jacq.), while at Za-zounmè, it was dominated by Imperata grass (*Imperata cylindrica*) during the fallow period. LR2018 and LR2019 cropping seasons were characterized by different rainfall patterns at both sites. The two sampled locations experienced their heavy rain from 1 May to 30 June for the 2 years. Cumulatively, 443 and 355 mm were recorded as rainfall amount during LR2019 and LR2018 at Dan (Table 1), respectively. A total of 34 and 32 rain events were observed, respectively, in LR2018 and LR2019. The average rainfall of the erosive rain events (i.e., events that are large enough to generate runoff, and therefore to create erosion) was 46.32 mm in LR2018 and 40.01 mm in LR2019 at Dan. LR2018 recorded more rainfall than LR2019 at Za-zounmè. Cumulatively, 620 mm (in 36 rain events) and 541 mm (in 27 rain events) were recorded, respectively, in LR2018 and LR2019. Za-zounmè experienced 24 erosive events in 2018, while 21 erosive events were observed in 2019.

Experimental design

The experiment was conducted during two major rainy seasons, 2018 (LR2018) and 2019 (LR2019). The experimental design at each site was arranged in a randomized complete block design. The treatments were replicated four times at each site. Three tillage practices: NT, slope ridging (SR), and contour ridging (CR) and four mulch doses: 0 $t{\cdot}ha^{-1}$ (0M), 3 $t{\cdot}ha^{-1}$ (3M), 5 $t{\cdot}ha^{-1}$ (5M), and 7 $t{\cdot}ha^{-1}$ (7M) were investigated. Maize stover (C:N ratio = 46) was applied for the mulch treatments. In all seasons, mulch levels of <3 $t{\cdot}ha^{-1}$ were used because cereal stover yields of up to 3 $t{\cdot}ha^{-1}$ are achievable on smallholder farms in central Benin (Saïdou et al. 2018; Akplo et al. 2020). Mulch levels of >3 $t{\cdot}ha^{-1}$ were selected to assess if there is any yield benefit in increasing surface cover beyond 2–4 $t{\cdot}ha^{-1}$, which normally gives the minimum 30% cover for CA systems (Erenstein 1997). Before the implementation of the treatments, the natural vegetation was removed with a machete. Being the farmer's practice, slope ridge (SR) system was used as control in this experiment. The ridges were manually constructed using hoe and tape measure and were a width of 60 cm, a height of 20 cm, and with an 80 cm-wide furrow between each ridge. The ridges were oriented up and down slope in the case of SR system (Fig. 2A), while oriented following the contour lines in the case of CR system (Fig. 2B). The plots of no-till treatment did not undergo any additional tillage. The seedpots were manually made with the hoe. Maize crop (*Zea maize* L.) was grown on the experimental plots.

To evaluate the runoff amount (RA) under the studied treatments, the "runoff plots" were established (Akplo et al. 2017; Bashagaluke et al. 2018). The size of each experimental plot was 6 m × 3.5 m and they were fenced by metal sheets embedded in the ground along all plot boundaries (Fig. 3). At the lower boundary of the plot, runoff water and eroded soil drained to a fractional sample collection device composed of two tanks. The first tank was connected to each plot by a PVC pipe with a 40 mm diameter. It is pierced in its upper part with eight identical holes and connected to the second tank by a PVC pipe of 20 mm diameter. The runoff and the eroded soil were exited from seven holes and only from one hole it drained to the second tank. Using this system, it was possible

Table 1. Erosive rainfall characteristics during the investigated cropping seasons.

Cropping season	Total rain fall (mm)	Number of rain events	Number of erosive events	Mean rain height of erosive events (mm)
Dan				
Major cropping season 2018	355.88	34	22	46.32 ± 18.20
Major cropping season 2019	446.83	32	20	40.01 ± 20.87
Za-zounmè				
Major cropping season 2018	620.60	36	24	42.58 ± 12.21
Major cropping season 2019	541.41	27	21	43.92 ± 6.64

Fig. 2. Studied ridging systems. (A) Slope ridging. (B) Contour ridging. [Colour online]

to determine the runoff rate, the fine suspended SL (fraction capable of migrating over a long distance), and the coarse soil particle loss (short-distance saltation).

Determination of runoff, runoff coefficient, soil loss, and nutrient loss

Runoff amount and runoff coefficient

Twenty rain events were targeted from 1 May to 30 June during the major rainy season of 2018 (LR2018) and 2019 (LR2019). The total volume of each rain event was measured using a rain gauge (iMETOS IMT280). Runoff was collected in the tanks with the installed receiving system. The runoff volume (V_r) was estimated as follows:

$$(1) \quad V_r = V_1 + (\beta \times V_2)$$

where V_1 is the volume of runoff in the first tank; V_2 is the volume of runoff in the second tank; and β is a constant associated with the number of holes of the first tank (in our case, $\beta = 8$). The RA (in $l.m^{-2}$) was determined by dividing the runoff volume (V_r) by the surface (m^2) of each plot as follows:

$$(2) \quad RA = V_r/\text{surface}$$

The runoff coefficient (RC) was estimated using the following equation:

$$(3) \quad RC\ (\%) = (V_r/V) \times 100$$

where V is the total rain mass (in litres)

Soil loss

The total amount of SL was calculated from the total dry amount of soil retained in the tank and the sediment concentration in the runoff. After each erosive rain event, sediments retained at the bottom of each tank were collected and weighed. A sample of 200 g was collected from the amount of soil retained in the tank and oven-dried at 105 °C for 48 h for determining the dry mass of soil retained in the tank (Q_1). Five hundred millilitre (500 mL) was sampled from the total runoff for quantifying the suspended sediment (Q_2). The sampled runoff was oven-dried at 105 °C for 48 h. Therefore, the total amount of SL (Q) under each treatment was delivered using eq. 4.

$$(4) \quad Q = Q_1 + Q_2$$

Q_1 and Q_2 were determined as follows (eq. 5):

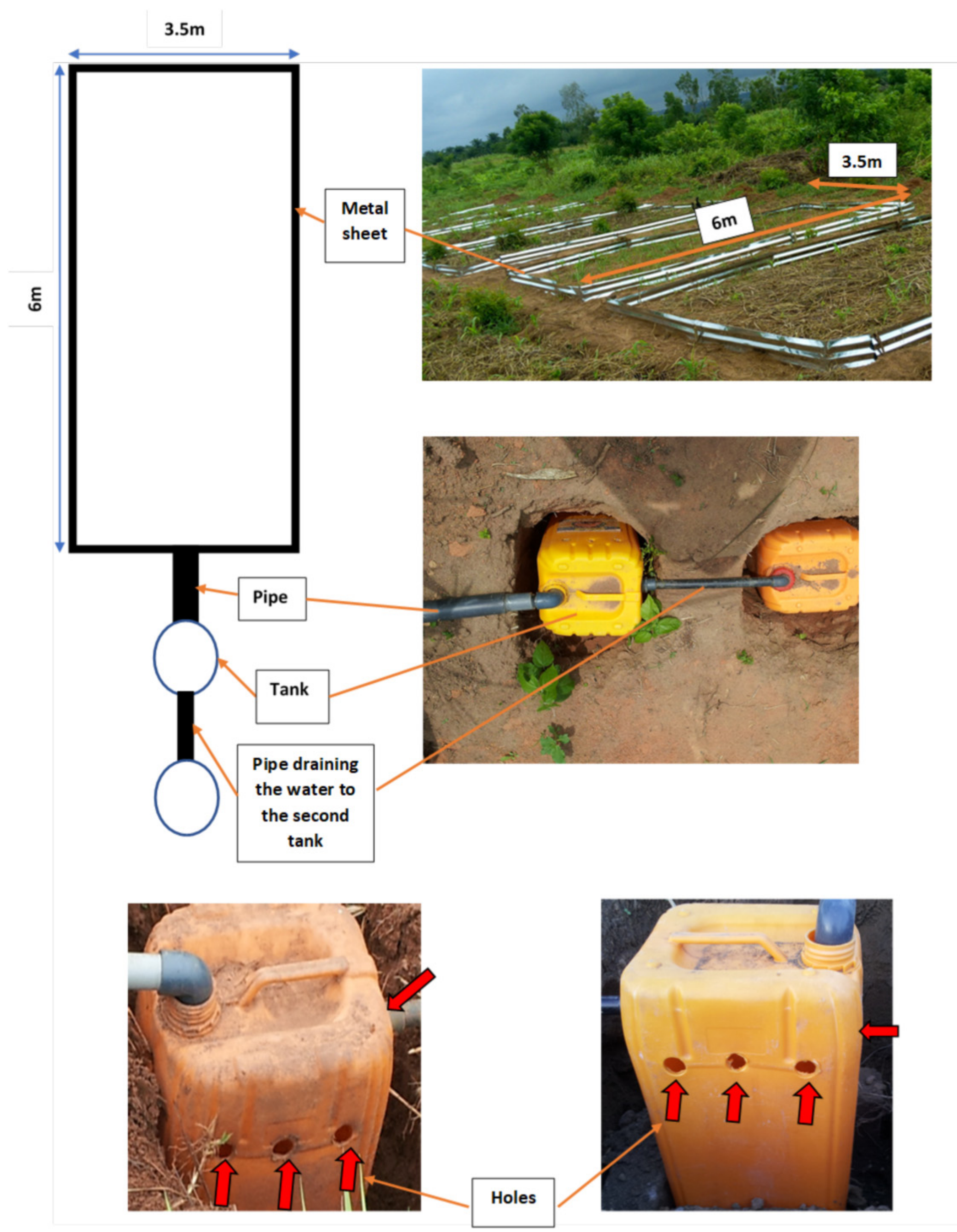
$$(5) \quad Q_1 = (b/a) \times C$$

where Q_1 is the total dry amount of sediment retained in the tank; a is the fresh weight (g) of the sediment sample measured in situ and taken for oven drying at 105 °C for 48 h; and b is the dry weight (g) of the sediment sample and C is the fresh weight of the sediment collected from the collecting tank and measured in the field.

$$(6) \quad Q_2 = (r_2/r_1) \times Rf$$

where Q_2 (g) is the total amount of suspended sediment; r_2 (g) is the mass of dry sediment in the aliquot that was oven-dried; and r_1 (ml) is the volume of runoff water sample and Rf (ml) is the total runoff measured on the field.

Fig. 3. Experimental field setup. [Colour online]



Nutrient loss

The amount of nutrient contained in sediment, NL (g), was computed using eq. 7:

$$\text{NL} = C \times Q \quad (7)$$

where C ($g \cdot kg^{-1}$) is the concentration of each element (N, available P, and exchangeable K) in the sediment and Q (kg) is the total amount of sediment lost.

Laboratory analysis

The soil sampled for baseline fertility characterization and the collected sediments were air-dried and sieved through a 2 mm mesh. Total nitrogen was determined by the Kjeldahl nitrogen fixation method (Kjeldahl 1883). Available phosphorus was estimated by the Bray I method (Bray and Kurtz 1945). Exchangeable potassium was extracted using 1 mol/L neutral ammonium acetate and determined by the atomic absorption spectrometry method. In addition, pH water (1:2.5), SOC, and particle size were determined in the soil samples. Soil pH was determined using the Mathieu and Pieltain (2003) protocol by mixing in a 50 mL beaker, 10 g of ground and sieved soil (0.2 mm mesh), and 25 mL of demineralized water and stirring the solution (soil water) using an agitator for 30 min. The soil pH was measured using a pH meter (Inolab 720). Particle size was determined by Robinson's method (Robinson 1922). Soil total C was measured by the Walkley and Black oxidation method (Walkley and Black 1934). The SOM was calculated using the formula SOM = carbon content × 1.72 (with 1.72 being the stable coefficient of cultivated soils) (Nelson and

Sommers 1996). Laboratory analyses were performed in the Laboratory of Soil Microbiology and Microbial Ecology of the Faculty of Agronomic Sciences of the University of Abomey-Calavi (Republic of Benin).

Determination of gravimetric moisture, bulk density, and saturated hydraulic conductivity

Within each investigated season, gravimetric soil moisture was determined in the top 20 cm of soil once per 2 weeks. The wet weight (P_h) of samples was determined in situ, whereas the dry weight (P_S) was determined in the laboratory after oven drying at 105 °C until a constant dry weight was attained. Soil moisture (GM) was determined by the following formula proposed by Anderson and Ingram (1993):

$$\text{(8)} \quad \text{GM}\,(\%) = [(P_h - P_s)\,/P_s] \times 100$$

For the bulk density (BD) determination, a volume of 100 cm^3 of soil sample was collected on the top 20 cm layer with stainless steel cores at the end of the experiment in 2019. The sample was oven-dried at 105 °C for 72 h for dry weight determination. The BD was then calculated using eq. 9:

$$\text{(9)} \quad \text{bulk density} = \text{dry weight (g)/volume}\,(\text{cm}^3)$$

The effect of tillage system and mulching on saturated hydraulic conductivity (SHC) of the soil was measured using a tension infiltrometer under laboratory conditions. Undisturbed soil samples were collected at the end of the experiment in 2019 using core samplers as described for soil BD. The core samples were placed on the top of a gauze and were saturated with water. The calculation of SHC (cm·h^{-1}) was done using the modified falling head equation as described in Bouwer and Rice (1976):

$$\text{(10)} \quad k_s = (L/t) \times [(L + h_0)\,/\,(L + h_1)]$$

where k_s is the hydraulic conductivity; L is the length of soil column; h_0 is the height of water above surface at time 0; and h_1 is the height of water above surface at the end and t is the time until the water level changed from h_0 to h_1.

Statistical analyses

A series of statistical analyses were performed. First, multisite-year mixed-effect analysis of variance (ANOVA) models matching the study design were conducted for each of the collected variables; site-year, tillage system, and mulch input rate effects as fixed effects; and tillage system nested in block nested in site-year as random effects. This first analysis showed a significant site-year effect. Given the significant site-year effect, a three-way ANOVA using PROC MIXED procedure was conducted for each year and on each site. Tillage system and mulch input rates were taken as a fixed effect, while block was considered as a random effect. Significant fixed effects were further dissected by extracting means and performing Tukey's Honestly Significant Difference pairwise comparisons with an alpha of 0.05. The normality and homogeneity of the data for each variable were tested by the Shapiro–Wilk test (Shapiro and Wilk 1965) and by Bartlett's test (Bartlett 1937), respectively. All statistical analyses were conducted in SAS 9.4 (SAS Institute 2013). Due to interactions between tillage and mulch input rates, the main effects were not reported.

Results

Runoff amount and runoff coefficient

The effects of the interaction between tillage and mulching were significant ($p < 0.001$) on the RA and RC in Dan and Za-zounmè and over both LR2018 and LR2019 cropping seasons (Table 2). Overall, SR with 0 t·ha^{-1} mulch (SR + 0M) and NT with 0 t·ha^{-1} mulch (NT + 0M) yielded the highest RA and RC, while CR with 7 t·ha^{-1} mulch (CR + 7M) was associated with the lowest values (Table 3). CR + 7M decreased RA and RC by 100% compared to the treatments. NT was found to be effective in runoff controlling when combined with a mulch quantity greater than 3 t·ha^{-1}. Of particular note, runoff is lower with CR than with SR and NT, whatever the amount of mulch. Also, regardless of tillage type, runoff decreased as the amount of mulch increased. However, no significant difference in RA and RC was observed when increasing the amount of mulch from 3 to 5 t·ha^{-1} for all of the tillage modalities.

SL under different tillage practices and mulch input rates

At both sites, the ANOVA showed significant interaction effects between tillage and mulching treatments on SL ($p < 0.05$) (Table 2). Over the LR2018 and LR2019 seasons, SL was lower under CR with 7 t·ha^{-1} mulch, CR + 7M, whereas higher SL was recorded under SR with 0 t·ha^{-1} mulch (SR + 0M) and NT with 0 t·ha^{-1} mulch (NT + 0M) (Table 4). More than 5 t·ha^{-1} were recorded as SL under SR + 0M (respectively, 5.45 t·ha^{-1} in Dan and 6.46 t·ha^{-1} in Za-zounmè) and NT + 0M (respectively, 6.84 t·ha^{-1} in Dan and 6.60 t·ha^{-1} in Za-zounmè) in LR2018 as well as under NT + 0M (6.06 t·ha^{-1}) at Dan in LR2019. Compared with the control (SR + 0M), SL reduction due to CR + 0M, CR + 3M, CR + 5M, and CR + 7M ranged between 55% and 100% in LR2018 and between 70 and 100% in LR2019 at Dan. At Za-zounmè, CR + 0M, CR + 3M, CR + 5M, and CR + 7M decreased SL by at least 70% in LR2018 and 66% in LR2019. Less SLs were observed under NT + 5M and NT + 7M, which reduced the SL, respectively, by more than 30% compared to SR + 0M at both sites. Mulch decreased SL for all three tillage treatments and this effect is pronounced especially if the amount of mulch is great. This clearly indicates the importance of mulch treatment in the reduced mobilization of soil particles. For example, for each tillage treatment, SL was low with 7 t·ha^{-1} of mulch (i.e., NT7M, SR7M, and CR7M).

Nutrients loss under different tillage practices and mulch input rates

Nitrogen (N), available phosphorus (P), and extractable potassium (K) were assessed in the course of the experiments as they have been largely documented as the major nutrients. The influence of tillage practices, mulch amounts, and

Can. J. Soil Sci. **102:** 659–671 (2022) | dx.doi.org/10.1139/CJSS-2021-0080

Table 2. ANOVA of tillage, mulching, and their interactions on runoff, soil loss, and soil properties.

		LR2018								LR2019						
Source	df	RA	RC	SL	N	P	K	RA	RC	SL	N	P	K	BD	GM	SHC
Dan																
Tillage (T)	2	***	***	***	***	***	**	***	***	***	***	***	**	ns	***	ns
Mulch input rate (M)	3	***	***	***	***	***	***	***	***	***	***	***	**	ns	*	ns
T×M	6	***	***	**	***	***	**	***	***	***	***	***	*	ns	***	ns
Bloc	3	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Model	14															
Error	81															
Corrected total	95															
Za-zounmè																
Tillage (T)	2	***	***	***	***	***	**	***	***	***	***	***	*	ns	*	ns
Mulch input rate (M)	3	***	***	***	***	*	*	***	***	***	***	***	*	ns	**	ns
T×M	6	***	***	***	*	*	*	***	***	*	***	***	*	ns	***	ns
Bloc	3	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Model	14															
Error	81															
Corrected total	95															

Note: BD, bulk density ($g \cdot cm^{-3}$); GM, gravimetric moisture (%); K, exchangeable potassium loss ($kg \cdot ha^{-1}$); N, total nitrogen loss ($kg \cdot ha^{-1}$); P, available phosphorus loss ($kg \cdot ha^{-1}$); RA, runoff amount ($L \cdot m^{-2}$); RC, runoff coefficient (%); SL, soil loss ($t \cdot ha^{-1}$); SHC, saturated hydraulic conductivity; ns, non significant; *, significant at $\alpha = 0.05$; **, significant at $\alpha = 0.01$; ***, significant at $\alpha = 0.001$.

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Table 3. Runoff amount (RA) and runoff coefficient (RC) under different tillage practices and mulch doses.

Treatment	Runoff amount (L·m^{-2})				Runoff coefficient (%)			
	Dan		Za-zounmè		Dan		Za-zounmè	
	LR2018	LR2019	LR2018	LR2019	LR2018	LR2019	LR2018	LR2019
CR + 0M	0.24c	0.24cd	0.24b	0.27b	0.46b	0.52b	0.58cd	0.54c
CR + 3M	0.17c	0.16cd	0.15b	0.27b	0.32b	0.98b	0.35d	0.52c
CR + 5M	0.13c	0.12cd	0.12b	0.12b	0.25b	0.23b	0.27d	0.24c
CR + 7M	0.00d	0.00cd	0.00b	0.00b	0.00b	0.00b	0.00d	0.00c
NT + 0M	2.91a	2.53a	1.17a	3.52a	5.78a	6.18a	5.35a	6.98a
NT + 3M	0.64b	0.75bc	0.53b	0.76b	1.27b	1.63b	1.86bc	1.56c
NT + 5M	0.57b	0.75bc	0.05b	0.62b	1.11b	1.31b	1.79bc	1.26c
NT + 7M	0.24c	0.25cd	0.05b	0.35b	0.48b	0.65b	0.59 cd	0.71c
SR + 0M	2.48a	1.17b	2.52a	2.44a	4.96a	5.12a	2.41b	4.94c
SR + 3M	0.54b	0.53bcd	0.75b	0.59b	1.13b	1.20b	1.12bcd	1.16b
SR + 5M	0.08d	0.05d	0.75b	0.17b	0.17b	0.30b	0.15d	0.35c
SR + 7M	0.16c	0.0d	0.24b	0.08b	0.34b	0.20b	0.13d	0.17c

Note: CR + 0M, contour ridging + 0 t·ha^{-1} mulch; CR + 3M, contour ridging + 3 t·ha^{-1} mulch; CR + 5M, contour ridging + 5 t·ha^{-1} mulch; CR + 7M, contour ridging + 7 t·ha^{-1} mulch; SR + 0M, slope ridging + 0 t·ha^{-1} mulch; SR + 3M, slope ridging + 3 t·ha^{-1} mulch; SR + 5M, slope ridging + 5 t·ha^{-1} mulch; SR + 7M, slope ridging + 7 t·ha^{-1} mulch; NT + 0M, no-tillage + 0 t·ha^{-1} mulch; NT + 3M, no-tillage + 3 t·ha^{-1} mulch; NT + 5M, no-tillage + 5 t·ha^{-1} mulch; NT + 7M, no-tillage + 7 t·ha^{-1} mulch. For each factor, the same lowercase letters denote no significant difference between the means at a given site. Means followed by letters of same characters within a column are not significantly different ($p > 0.05$) (Tukey's HSD test).

Table 4. Total soil loss (SL) under different tillage practices, mulch doses, and tillage × mulch doses.

Treatment	Dan		Za-zounmè	
	LR2018	LR2019	LR2018	LR2019
CR + 0M	1.21cde	2.44bc	1.91cde	1.67cd
CR + 3M	1.07cde	2.45bc	1.21def	1.33cd
CR + 5M	0.94cde	2.70bc	0.76ef	1.14cd
CR + 7M	0.00e	0.00f	0.00f	0.00d
NT + 0M	6.06a	6.84a	3.15bc	6.60a
NT + 3M	3.57b	5.32ab	5.42a	5.18ab
NT + 5M	2.49bcd	3.36abc	3.69b	3.13bc
NT + 7M	0.57de	1.84bc	0.86ef	1.54cd
SR + 0M	4.46ab	5.45ab	6.46a	4.90ab
SR + 3M	3.13bc	3.44abc	2.47bcd	5.32ab
SR + 5M	1.19cde	3.62abc	0.70ef	2.38cd
SR + 7M	1.21cde	0.62c	0.75ef	0.63cd

Note: CR + 0M, contour ridging + 0 t·ha^{-1} mulch; CR + 3M, contour ridging + 3 t·ha^{-1} mulch; CR + 5M, contour ridging + 5 t·ha^{-1} mulch; CR + 7M, contour ridging + 7 t·ha^{-1} mulch; SR + 0M, slope ridging + 0 t·ha^{-1} mulch; SR + 3M, slope ridging + 3 t·ha^{-1} mulch; SR + 5M, slope ridging + 5 t·ha^{-1} mulch; SR + 7M, slope ridging + 7 t·ha^{-1} mulch; NT + 0M, no-tillage + 0 t·ha^{-1} mulch; NT + 3M, no-tillage + 3 t·ha^{-1} mulch; NT + 5M, no-tillage + 5 t·ha^{-1} mulch; NT + 7M, no-tillage + 7 t·ha^{-1} mulch. For each factor, the same lowercase letters denote no significant ($p > 0.05$) difference between the means at a given site according to the Tukey's HSD test.

their interaction were significant ($p < 0.05$) on N, P, and K lost through erosion over the LR2018 and LR2019 seasons at the two sampled sites (Table 2). The nutrients lost under as affected by the interaction between tillage practices and mulching input rates are presented in Table 5. Among the treatments, for all nutrients (i.e., N, P, and K), the lowest losses occurred due to CR + 7M. The nitrogen losses were significantly higher with SR with 0 t·ha^{-1} mulch (SR + 0M) in Dan (105.27 kg.ha^{-1} in LR2018 and 84.80 kg.ha^{-1} in LR2019) and in Za-zounmè (58.14 kg.ha^{-1} in LR2018 and 82.86 kg.ha^{-1} in LR2019). The difference observed under CR + 3M, CR + 5M, SR + 5M, SR + 7M, NT + 3M, and NT + 7M was not significant at Dan in LR2018. In LR2019, the difference between the N loss under NT + 3M and NT + 5M and the difference between the N loss under CR + 0M, CR + 3M, and CR + 5M were not significant. In Za-zounmè, treatments NT + 7M, SR + 5M, and SR + 7M on the one hand and treatments CR + 3M and CR + 5M on the other hand were not significantly different in LR2018, while CR + 0M, CR + 3M, CR + 5M, and SR + 5M were not significantly different in LR2019.

In contrast to N loss, the difference occurred among the treatment was less pronounced for P loss. Phosphorus loss was the highest under NT with 0 t·ha^{-1} mulch (NT + 0M) at Dan in LR2018 and LR2019, while its value was the greatest under SR + 0M at Za-zounmè. For SR, mulch had no significant effect on phosphorus loss at Dan in LR2018 and the average value was 0.99 kg·ha^{-1}. Also, the difference due to treatments CR + 0M, CR + 3M, and CR + 5M was not significant at Dan LR2018. In LR2019, phosphorus losses due to treatments CR + 7M, SR + 7M, and NT + 7M were not significantly different and were the lowest. At Za-zounmè, CR + 3M, CR + 5M, CR + 7M, SR + 7M, and NT + 7M showed low values of phosphorus loss (<0.5 kg·ha^{-1} in LR2018 and <2 t·ha^{-1} in LR2019).

More potassium was lost under NT + 0M, NT + 3M, and SR + 3M. Overall, increasing mulch input rate resulted in a decreasing trend of losses. However, the difference between 3 and 5 t·ha^{-1} (e.g., CR + 3M and CR + 5M in LR2018 at Dan) and between 5 and 7 t·ha^{-1} mulch (e.g., SR + 5M and SR + 7M in LR2018 at Dan and in LR2019 at Za-zounmè) were sometimes not significant. NT + 7M (i.e., NT with 7 t·ha^{-1} mulch) significantly reduced (<0.5 kg·ha^{-1}) potassium loss at both sites.

Can. J. Soil Sci. **102**: 659–671 (2022) | dx.doi.org/10.1139/CJSS-2021-0080

Table 5. Nitrogen, phosphorus, and potassium losses under different tillage practices, mulch doses, and tillage × mulch doses.

Treatment	Total nitrogen (kg·ha^{-1})				Available phosphorus (kg·ha^{-1})				Exchangeable potassium (kg·ha^{-1})			
	Dan		Za-zounmè		Dan		Za-zounmè		Dan		Za-zounmè	
	LR2018	LR2019	LR2018	LR2019	LR2018	LR2019	LR2018	LR2019	LR2018	LR2019	LR2018	LR2019
CR + 0M	51.12bc	20.11de	23.33cde	16.70def	0.78cd	1.94d	1.26b	1.39cd	1.05d	1.92bc	1.61a	1.38bc
CR + 3M	14.98d	23.3de	9.94ef	17.00def	0.43cd	1.89d	0.33c	1.41cd	0.78de	1.96bc	0.48ab	1.58bc
CR + 5M	13.61d	20.29de	12.28ef	17.62def	0.49cd	1.63d	0.18c	1.66cd	0.64de	2.20b	0.82bc	1.76bc
CR + 7M	0.00d	0.00e	0.00e	0.00f	0.00d	0.00e	0.00d	0.00d	0.00e	0.00d	0.00d	0.00d
NT + 0M	64.96b	53.46b	43.86abc	54.94b	5.34a	6.98a	1.12b	2.45c	3.04b	5.51a	2.06b	4.87a
NT + 3M	42.26c	46.13bcd	52.91ab	43.00bc	3.66b	4.42c	1.03b	5.02a	4.41a	4.38a	3.93a	4.03a
NT + 5M	39.18c	30.39bcd	32.51bcd	27.72cde	1.01cd	2.98d	1.31b	2.96bc	2.42bc	2.70b	2.50b	2.11b
NT + 7M	10.25cd	16.87de	13.91def	14.20ef	0.18d	0.61e	0.48c	1.28cd	0.35de	0.46c	0.53c	1.13c
SR + 0M	105.27a	84.80a	58.14a	82.86a	1.38cd	2.12d	2.93a	6.12a	2.01c	2.59b	1.53bc	2.68b
SR + 3M	60.01b	45.54bc	52.91ab	41.99bcd	1.02cd	5.46b	1.18b	4.39ab	2.58bc	4.29a	4.47a	4.06a
SR + 5M	14.94d	27.36cd	32.51def	17.8def	0.73cd	3.42c	0.91b	1.43cd	1.07d	2.37b	0.41c	1.69bc
SR + 7M	11.18d	5.39ef	15.65def	3.52ef	0.83cd	0.59e	0.33c	0.18d	1.00d	0.43c	0.37c	1.24bc

Note: CR + 0M, contour ridging + 0 t·ha^{-1} mulch; CR + 3M, contour ridging + 3 t·ha^{-1} mulch; CR + 5M, contour ridging + 5 t·ha^{-1} mulch; CR + 7M, contour ridging + 7 t·ha^{-1} mulch; SR + 0M, slope ridging + 0 t·ha^{-1} mulch; SR + 3M, slope ridging + 3 t·ha^{-1} mulch; SR + 5M, slope ridging + 5 t·ha^{-1} mulch; SR + 7M, slope ridging + 7 t·ha^{-1} mulch; NT + 0M, no-tillage + 0 t·ha^{-1} mulch; NT + 3M, no-tillage + 3 t·ha^{-1} mulch; NT + 5M, no-tillage + 5 t·ha^{-1} mulch; NT + 7M, no-tillage + 7 t·ha^{-1} mulch. For each factor, the same lowercase letters denote no significant ($p > 0.05$) difference between the means at a given site according to the Tukey's HSD test.

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Soil bulk density, gravimetric moisture, and saturated hydraulic conductivity as affected by different tillage practices and mulch input rates

Soil BD and SHC were not significantly ($p > 0.05$) affected by the tillage practices or mulch input rates as well as their interaction (Table 2). Conversely, the gravimetric moisture (GM) was significantly ($p < 0.001$) affected by the interaction between tillage and mulch input rates. The soil moisture of topsoil was very low at both sites, especially at Za-zounmè (6.24%–12.07%) but also at Dan (12.55%–16.98%). Statistical differences were observed between the treatments at both Dan and Za-zounmè (Table 6). At both sites, the gravimetric soil moisture content was lowest on the NT + 0M plots at Dan (12.55%) and on SR + 0M (6.24%) at Za-zounmè and highest on the CR + 7M plots (16.98% at Dan and 12.07 at Za-zounmè). Overall, contour ridge treatments stored more moisture in the soil than NT and slope ridge.

Discussion

For agriculture to meet the growing needs of adequate food and textiles for an ever-increasing human population, there will be increasing demand to efficiently maximize the usage of arable land through the adoption of sustainable agricultural practices (Lizotte and Locke 2018). Therefore, good soil management practices in agricultural watersheds must be implemented. The results of this study showed a significant effect of the interaction between different tillage practices and mulch input rates on soil erosion (runoff, RA, and SL) and nutrients loss (N, P, and K). During the two seasons of experimentation (i.e., LR2018 and LR2019), RA, RC, and SL under CR treatments were significantly less than those of NT and SR treatments at both sites. Consequently, the lowest nutrient losses were observed with CR treatments. In the CR system, ridges are made following the contour lines and serve as obstacles for the runoff by reducing the velocity of water (Uwizeyimana et al. 2018). Conversely, SR showed the highest runoff rates since it is oriented in slope direction. This finding confirms the importance of tillage practices in erosion control. Kiboi et al. (2019) argued that appropriate tillage practices constitute important management tools to combat water erosion risks, to promote in situ water conservation, crop yield improvement, and stabilization in rainfed systems in semiarid and subtropical regions. The findings corroborate those of Kouelo (2016) and Akplo et al. (2017). Soil erosion reduction effect of NT practice has been documented frequently and is mostly attributed to increased organic carbon content and the retention of crop residues at the soil surface (Kasper et al. 2009). However, this effect was not observed in this study. High soil erosion may have been observed under NT in this study because it was implemented immediately prior to this study. Generally, the conservation tillage practices are associated with a transition phase of 7–8 years (on average) characterized by high soil erosion (Pagnani et al. 2019). Time is required for developing continuous macropores and improving aggregate stability in soils undisturbed by tillage. The surprising result is also the higher runoff on NT plots as compared to SR plots. It is expected that runoff should be lower on NT treatments, but it need not to be always the case. In this study, the SR treatments generated lower runoff than NT mainly because the ridges had very large size (60 cm wide and 20 cm high) and were created by hand labor (using hoe). Such way, the ridges were very loose and contain huge amount of large macropores, and the surface roughness was very high in both ridges and furrows. Considering that the vegetation season is rather short in tropical agroecosystems (April until July), there was little time for soil to get compacted. Therefore, considering this loose consistency and great surface roughness at CR plot and also smooth slope of the NT plots most water infiltrated into the ridges or stagnated in depressions in furrows and only small runoff was generated. Overall, the lowest values of soil erosion were obtained with 5 and 7 $t{\cdot}ha^{-1}$ mulch plots (i.e., CR + 5M, CR + 7M, NT + 5M, NT + 7M, SR + 5M, and SR + 7M). This is consistent with other studies that found higher crop residue cover reduced soil erosion (Schiettecatte et al. 2008; Bashagaluke et al. 2019). This vegetal mulch protects the soil from the raindrop impact. As a result, the soil is protected against crusting, its roughness is increased while runoff stream, and the sediment transport capacity is decreased (Findeling et al. 2003; Schiettecatte et al. 2008). This effect of mulching on soil erosion was confirmed by Mazarei and Ahangar (2013) and Houngnandan et al. (2018). As suggested by Guto et al. (2012), the role of cover crop systems in soil erosion control is based on both principles of minimizing the effects of rainfall on the soil surface and reducing the volume and velocity of runoff on the soil surface. Apart from providing better soil surface protection as cover crops (Fageria et al. 2005), through the reduction in the mechanical impact of raindrops on the soil surface, mulch may be lost as litter during the growth period with a positive effect on soil infiltration through soil porosity and structure improvement (Govaerts et al. 2009). However, to have real benefit from mulch, a great quantity should be applied. The best mulch amounts observed in our study are similar with Mupangwa et al. (2007), who suggested at least 4 $t{\cdot}ha^{-1}$ of mulch. Le Bissonnais et al (2005) reported that below 20% of coverage, the canopy or residues do not provide sufficient and continuous protection against raindrop impact and particle detachment by runoff.

Our results indicated that soil BD and SHC of the soil were not significantly affected by the tested tillage systems and mulch doses. However, GM was affected. The lack of differences in BD and SHC between treatments (i.e., tillage practices × Mulching) could be because of the short duration of the experimental study. These findings were similar with a growing body of studies over the past year that established that changes in soil physical properties require time. For example, Gura and Mnkeni (2019) and Nebo et al. (2020) observed no significant difference in the soil BD between NT and conventional tillage systems. More so, Hu et al. (2016) observed that under a continuous NT system, it takes at least at 5 years for soil properties to fully stabilize. Zhang et al. (2007) found, after 24 years, significantly greater macropores (more than 11%) under no-till with residue retention than under conventional tillage with residue burnt. As concerning the effect of the mulching, it also needs more time for maize straw (C:N ratio = 46) decomposition. The present experi-

Table 6. Impact of tillage and mulch doses on soil bulk density, gravimetric moisture, and soil saturated hydraulic conductivity.

Treatment	Bulk density ($g \cdot cm^{-3}$)		Gravimetric moisture (%)		Saturated hydraulic conductivity ($cm \cdot h^{-2}$)	
	Dan	Za-zounmè	Dan	Za-zounmè	Dan	Za-zounmè
CR + 0M	1.4	1.33	15.08bc	6.82cde	2.4	2.19
CR + 3M	1.39	1.33	15.68b	6.99cde	2.22	2.01
CR + 5M	1.38	1.35	16.29b	7.32bcd	2.2	2.13
CR + 7M	1.39	1.35	16.98a	12.07a	2.58	2.92
NT + 0M	1.54	1.3	12.55d	6.33de	2.49	2.09
NT + 3M	1.48	1.32	13.21d	6.54de	2.12	2.59
NT + 5M	1.42	1.48	13.08d	7.31bcd	2.48	2.43
NT + 7M	1.4	1.4	13.86dc	8.24bc	2.67	2.59
SR + 0M	1.55	1.45	14.97bc	6.24e	2.32	2.38
SR + 3M	1.51	1.33	13.72cd	6.4de	2.32	2.56
SR + 5M	1.48	1.32	13.79cd	7.75bcd	2.42	2.45
SR + 7M	1.45	1.34	15.21bc	8.55b	2.48	2.01

Note: CR + 0M, contour ridging + 0 $t \cdot ha^{-1}$ mulch; CR + 3M, contour ridging + 3 $t \cdot ha^{-1}$ mulch; CR + 5M, contour ridging + 5 $t \cdot ha^{-1}$ mulch; CR + 7M, contour ridging + 7 $t \cdot ha^{-1}$ mulch; SR + 0M, slope ridging + 0 $t \cdot ha^{-1}$ mulch; SR + 3M, slope ridging + 3 $t \cdot ha^{-1}$ mulch; SR + 5M, slope ridging + 5 $t \cdot ha^{-1}$ mulch; SR + 7M, slope ridging + 7 $t \cdot ha^{-1}$ mulch; NT + 0M, no-tillage + 0 $t \cdot ha^{-1}$ mulch; NT + 3M, no-tillage + 3 $t \cdot ha^{-1}$ mulch; NT + 5M, no-tillage + 5 $t \cdot ha^{-1}$ mulch; NT + 7M, no-tillage + 7 $t \cdot ha^{-1}$ mulch. For each factor, the same lowercase letters denote no significant ($p > 0.05$) difference between the means at a given site according to the Tukey's HSD test.

ment covered only 2 years, which is not sufficient for maize straw to be decomposed and hence influence soil BD and SHC. Mulch has the potential to enhance the total soil porosity (Mulumba and Lal 2008; Khoramizadeh et al. 2021) after decomposition and hence decrease BD (Hati et al. 2006). Findings from the present study showed that CR, SR, and NT with 7 $t \cdot ha^{-1}$ recorded the highest GM on both the experimental fields. This means that reducing the soil erosion (runoff and SL), these treatments conserved soil moisture. This was in agreement with previous studies (Akplo et al. 2020). The advantages of mulch are widely recognized (Araya et al. 2015; Toom et al. 2019). Crop residues as mulch at the soil surface increase carbon sequestration (Balesdent et al. 2000), maintain soil moisture, and aid in maintaining high soil biological activity (Mazarei and Ahangar 2013).

Based on our results, NT with 7 $t \cdot ha^{-1}$ mulch (NT + 7M) and CR with 7 $t \cdot ha^{-1}$ mulch (CR + 7M) could be recommended as conservation measures against runoff, SL, and nutrients in central Benin. Farmers should retain in situ straw of maize; residues of soybean or other residues of the previous crop and the seeding of the next crop should be done without soil tillage or on ridges following the contour.

Conclusion

Soil erosion curbing and water conservation constitute key challenges for achieving food security in Sub-Saharan Africa. The present study explored the efficiency of two conservation practices in water conservation and erosion control in central Benin. Results show that tillage and mulch doses significantly influence runoff, soil erosion, and nutrient loss. At both studied sites, NT with 7 $t \cdot ha^{-1}$ mulch (NT + 7M) and CR with 7 $t \cdot ha^{-1}$ mulch (CR + 7M) were associated with low soil erosion and nutrient loss. They were also associated with the highest GM values. This suggests that these practices could be an option for water conservation and erosion control. CR is an efficient measure, and it can be done by small traditional farmers by hand labor (using hoe) and although this approach is labor demanding its major advantage is that it does need special equipment or other investment. This study introduces the possibility of soil conservation and erosion controlling using NT in Benin. However, the feasibility of NT for smallholder farmers in Benin can be constrained by biophysical, socio-economical, and technical challenges. First of all, farmers must be properly trained on the NT since it requires increased knowledge of the system and adaptation to the site and farming circumstances. In addition, they should provide the appropriate machinery for sowing in NT system. However, two vegetation seasons are rather short period and the medium- and long-term impacts of NT require further research. Longer term study might show that the performance of no-till would improve relative to CR.

Acknowledgements

We acknowledge and thank to the reviewers for their detailed comments that helped us to improve the manuscript. We are also grateful to Habib Dèhoué, Marc-André Klotoé, and Jaurès Hounkonnou for their help during the fieldwork.

Article information

History dates

Received: 18 June 2021
Accepted: 12 January 2022
Accepted manuscript online: 16 February 2022
Version of record online: 11 August 2022

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Author information

Competing interests

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. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

Funding information

This work was financially supported by International Foundation for Science (IFS) through the Individual Grant N° I-1-C-6138–1 intituled “Évaluation des effets du semis direct sous couvert végétal sur l'érosion hydrique du sol et la productivité du maïs au Bénin”, provided to the first author. We are grateful to the International Atomic Energy Agency (IAEA), which provided the equipment used for laboratory analysis, through the Regional Project RAF5075 ”Enhancing regional capacities for assessing soil erosion and the efficiency of agricultural soil conservation strategies through fallout radionuclides".

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