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Effect of no-tillage on soil redistribution estimated by beryllium-7, soil moisture, and carbon fractions loss in central Benin

Tobi Moriaque Akplo[1] | **Félix Kouelo Alladassi**[1] | **Mahougnon Charlotte Carmelle Zoundji**[1,2] | **Emil Fulajtar**[3] | **Moncef Benmansour**[4] | **Naïvo Rabesiranana**[5] | **Folorunso Mathew Akinseye**[6] | **Pascal Houngnandan**[1,2]

[1]Research Unity of Soil Microbiology and Soil Conservation, Laboratory of Soil Sciences, Faculty of Agronomic Sciences, University of Abomey-Calavi, Abomey-Calavi, Benin

[2]School of Crop and Seed Production and Management, National University of Agriculture, Kétou, Benin

[3]Joint FAO/IAEA Centre of Nuclear Techniques in Food and Agriculture, International Atomic Energy Agency, Vienna, Austria

[4]Soil-Water-Climat Division, National Centre of Energy, Nuclear Sciences and Technologies (CNESTEN), Rabat, Morocco

[5]Institut National des Sciences et Techniques Nucléaires (INSTN), Antananarivo, Madagascar

[6]International Crop Research Institute for the Semi-Arid Tropics (ICRISAT), Thiès, Senegal

Correspondence

Tobi Moriaque Akplo, Research Unity of Soil Microbiology and Soil Conservation, Laboratory of Soil Sciences, Faculty of Agronomic Sciences, University of Abomey-Calavi, Abomey-Calavi, Abomey-Calavi, Benin.
Email: moriaqueakplo@gmail.com

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Abstract

Soil erosion has become one of the most common environmental problems and threatens food security. This study assessed the short-term effect of tillage and mulch on soil redistribution using the beryllium-7 method, soil moisture distribution, and soil organic carbon loss through soil erosion in typical agroecological conditions of Benin. The experiment was conducted on acrisols (at Dan) and ferralsols (at Za-zounmè) in central Benin. Three tillage practices slope ridging (SR), contour ridging (CR), and no-tillage (NT), and three mulch doses 0 (0 M), 3 (3 M), and 7 t ha^{-1} (7 M) on soil erosion under maize were investigated. The results showed a tillage and mulch interaction significantly ($p < 0.05$) influencing the soil redistribution, the loss of total carbon, the carbon of the particulate organic matter (C_POM), and the carbon content of the fine organic matter (C_MOM). High soil erosion was observed under SR0M (−10.19 t ha^{-1}) at Dan and under NT0M (−7.36 t ha^{-1}) at Za-zounmè. NT7M (0.80 t ha^{-1}), SR7M (0.69 t ha^{-1}), CR3M (2.07 t ha^{-1}), and CR7M (4.05 t ha^{-1}) showed deposition at Dan, while SR7M (0.23 t ha^{-1}), NT7M (1.69 t ha^{-1}), and CR7M (3.93 t ha^{-1}) showed deposition at Za-zounmè. C_MOM was lost on both

Abbreviations: ANOVA, analysis of variance; ^{7}Be, beryllium-7; C_MOM, carbon of the fine organic matter; C_POM, carbon of the particulate organic matter; CA, conservation agriculture; CR, contour ridging; CR0M, Contour ridging + 0 t ha^{-1} of mulch; CR3M, Contour ridging + 3 t ha^{-1} of mulch; CR7M, Contour ridging + 7 t ha^{-1} of mulch; FRNs, fallout radionuclides; NT, no-tillage; NT0M, no-tillage + 0 t ha^{-1} of mulch; NT3M, no-tillage + 3 t ha^{-1} of mulch; NT7M, no-tillage + 7 t ha^{-1} of mulch; SL, sediment lost; SOC, soil organic carbon; SR, slope ridging; SR0M, slope ridging + 0 t ha^{-1}; SR3M, slope ridging + 3 t ha^{-1} of mulch; SR7M, slope ridging + 7 t ha^{-1} of mulch.

sites. Mulch increases soil moisture for all three tillage treatments, and this effect is well pronounced especially if the amount of mulch is great. This study revealed useful information to be taken into consideration when developing soil and water conservation management strategies in Benin.

1 | INTRODUCTION

Soil erosion is one of the most important challenges facing humanity (Alewell et al., 2019; Panagos et al., 2016). Previously, it has been estimated that 56% of the world's soils are under the threat of mild-to-severe water erosion (Oldeman et al., 1991). Erosion is pronounced especially in semiarid and tropical environments, and thus more than 75% of the degraded land is in developing countries (Mabit et al., 2014), where soil erosion degrades 5–6 million ha annually and affects millions of people (Assefa, 2009; FAO, 2002). In Benin forest destruction, land overexploitation and unsuitable agricultural practices have contributed to great land degradation (Avakoudjo et al., 2021). As a result, most of the agroecological zones in Benin are characterized by high erosion (Akplo et al., 2022). Erosion results in declining soil fertility and decreasing crop yields (Saïdou et al., 2012). Consequently, crops most important for the food security of local populations (such as maize) are highly impacted (Saïdou et al., 2018). Maintaining food security in Benin requires soil conservation strategies to minimize soil erosion and its subsequent soil fertility decline.

Conservation agriculture (CA) practices are considered an alternative to traditional agricultural practices to improve food security and reduce agricultural-related soil degradation (Badgley et al., 2007; Farooq & Siddique, 2015). Conservation tillage and mulching are the most widely adopted soil conservation practices (Vincent-Caboud et al., 2019). Reducing soil erosion and increasing soil organic carbon (SOC) content, root length and density, and soil water storage are the main outcomes of NT practices (Fiorini et al., 2018; Lal, 2004). Crop residues as mulch at the soil surface provide shade, protect the soil surface against mechanical impact of raindrops and limit the surface runoff (Bashagaluke et al., 2018), increase carbon sequestration (Balesdent et al., 2000), preserve soil moisture, and supports high soil biological activity (Douzet et al., 2010; Mazarei & Ahangar, 2013).

In Benin, contour ridging (CR) and slope ridging (SR) are the most common traditional tillage practices (Akplo et al., 2019). The ridges are formed manually using hoe and tape measure, and they are 50–80 cm wide and 20–30 cm high. The ridges are oriented from up to down the slope in the case of the SR system or along the contour lines in the case of the CR system. No-tillage (NT) and mulching practices have been promoted, but their adoption by farmers remains limited (Akplo et al., 2019). In the specific climatic context of central Benin, NT and mulching practices can be useful in addressing the challenges of soil erosion reduction and water conservation. However, traditions and mindset, along with a lack of technical knowledge, are major constraints for CA systems adoption in Benin (Akplo et al., 2019). Smallholder farmers are very conservative, relying on methods passed down from generation to generation and deeply entrenched in their traditional way of life (Akplo et al., 2022). Then, the most crucial stage for soil conservation in Benin is to provide information on appropriate soil erosion management measures.

Erosion plots can provide valuable insights into erosion rates on site and the impact of different soil types, crops, and tillage systems, but they are insufficient for analyzing the spatially distributed information needed to explore soil redistribution patterns. Controlling all factors in field experiments and achieving an adequate representation of spatial and temporal patterns are challenging owing to the complex functioning of erosion processes (Boix-Fayos et al., 2006). The plot size (width and length) is very important; rate measurements at small and medium plot scales can be used to calculate soil loss, while larger scales can be used to assess sediment yield (Hudson, 1993; Stroosnijder, 2005). However, many developing nations face a lack of resources when it comes to establishing institutionalized land care and watershed development programs in order to implement long-term soil erosion measurement (Mabit et al., 2014). The quest for alternative techniques of soil erosion assessment to complement existing methods and meet new requirements has directed attention to a particular group of environmental radionuclides, namely fallout radionuclides (FRNs). The use of FRNs can complement and in some cases even substitute conventional measurements to evaluate erosion and sedimentation processes for developing and improving land management and soil conservation measures (Benmansour et al., 2013; Dercon et al., 2012; Gaspar & Navas, 2013; Mabit et al., 2008; Porto & Walling, 2012; Walling, 2006; Zapata, 2002). Beryllium-7 (^{7}Be, $t_{1/2}$ = 53.3 days) is a cosmogenic radionuclide produced in the upper atmosphere and lower stratosphere by cosmic ray spallation of nitrogen and oxygen. Because of its short half-life, it has the potential to quantify the effects of land use and land management on soil erosion rates and evaluate the efficiency of soil conservation measures (Mabit & Blake, 2019). Further, ^{7}Be is able to evaluate a micro-spatial variation in erosion at the field scale (Mabit et al., 2008; Ryken et al., 2018; Schuller et al., 2006).

The primary goal of the study was to assess the short-term impact of different tillage practices and mulch amounts on soil erosion (estimated by ^{7}Be) and SOC loss through erosion in typical agroecological conditions of Benin. All observations and measurements were done on experimental plots under natural precipitation. Our hypothesis was that both tested conservation measures NT and CR combined with mulching should reduce soil erosion and SOC loss through erosion.

Core Ideas

- The application of ^{7}Be provides accurate information on the effects of land management on soil erosion rates.
- Contour ridging and no-tillage combined with 3–7 t ha^{-1} of mulch reduced soil erosion and increased soil moisture.
- Fine organic matter was the most lost.
- To have real benefit from mulch, a 3–7 t ha^{-1} should be applied.
- There is a positive correlation between soil erosion and the loss of organic carbon fractions.

2 | MATERIALS AND METHODS

2.1 | Study area and experiment period

Two experimental sites were selected in central Benin: Dan (7°21′35″ N; 002°05′09″ E) and Za-zounmè (7°12′50″ N; 002°15′40″ E). Before implementing the experiments, both sites were fallowed since 2000 without any tillage, but farmers frequently burned the natural vegetation that grows after the rainy season resumes. The soils of Dan are classified as Acrisol, while those of Za-zounmè are classified as Ferralsol (IUSS Working Group WRB, 2015). The slope inclination is 5% at Dan and 4.6% at Za-zounmè. A baseline soil fertility reference was collected along the diagonal of each site at a depth of 0–20 cm and analyzed at the Laboratory of Soil Microbiology and Microbial Ecology of the Faculty of Agronomic Sciences of the University of Abomey-Calavi (Republic of Benin). Total nitrogen was determined by the Kjeldahl nitrogen fixation method (Kjeldahl, 1883). Available phosphorus was estimated by the Bray I method (Bray & Kurtz, 1945). Exchangeable potassium was extracted using 1 mol/L neutral ammonium acetate and determined by the atomic absorption spectrometry method. Soil pH water (1:2.5) was determined using (Mathieu and Pieltain's 2003) protocol. Particle size was determined by Robinson's method (Robinson, 1922). Soil total C was measured by the Walkley and Black oxidation method (Walkley & Black, 1934).

The characteristics of the soils at the experimental sites are shown in Table 1. The soil at Dan consists of sandy-clay-loam, with an acidic pH, and is moderately rich in organic matter, exchangeable potassium, available phosphorus, and total nitrogen. The water infiltration rate is very low. At Za-zounmè, the soil is sandy loam and has a pH close to neutral. The organic matter content, exchangeable potassium, available phosphorus, total nitrogen content, and water infiltration rate were moderate for this site.

Rains stations were installed within 30 m from the study sites and used to collect daily rainfall data. In both sites, the average annual rainfall is 1200 mm with a bimodal pattern of rainfall distribution defining two cropping seasons: major (March–July) and minor (September–November). The rainfall record for the period between January 1 and October 31, 2018, is shown in Figure 1. After a prolonged dry period from November to March, a rainy period followed from March to July 2018 and was characterized by a total rainfall of 598.7 mm in 44 days at Dan and 736 mm in 35 days at Za-zounmè. In August, a short dry season occurred followed by a period of very heavy rainfall from September to October. In this period, 321.3 mm of rainfall was recorded in 29 rain events at Dan, and 220 mm of rainfall was recorded in 16 rain events at Za-zounmè. The targeted period of the present study was September–October. Cropping systems are based on food crops, mainly maize (*Zea mays*) and soybeans (*Glycine max*) (Aholoukpè et al., 2020). These crops are planted in monoculture or in association or rotation with other crops such as cotton (*Gossypium* sp.).

TABLE 1 Characteristics of the experimental sites.

Sites	Dan	Za-zounmè
Type of soil	Acrisol	Ferralsol
pH (water 1:2.5)	5.63	6.40
Total nitrogen (g kg^{-1})	0.88	0.69
Organic matter (g kg^{-1})	13.7	12.4
Available phosphorus (mg kg^{-1})	12.6	18.12
Exchangeable potassium (ppm)	129.03	140.76
Water infiltration rate (cm day^{-1})	41	120
Clay (%)	25.20	14.19
Loam (%)	13.10	16.90
Sand (%)	61.70	68.91
Soil texture	Sandy-clay-loam	Sandy-loam

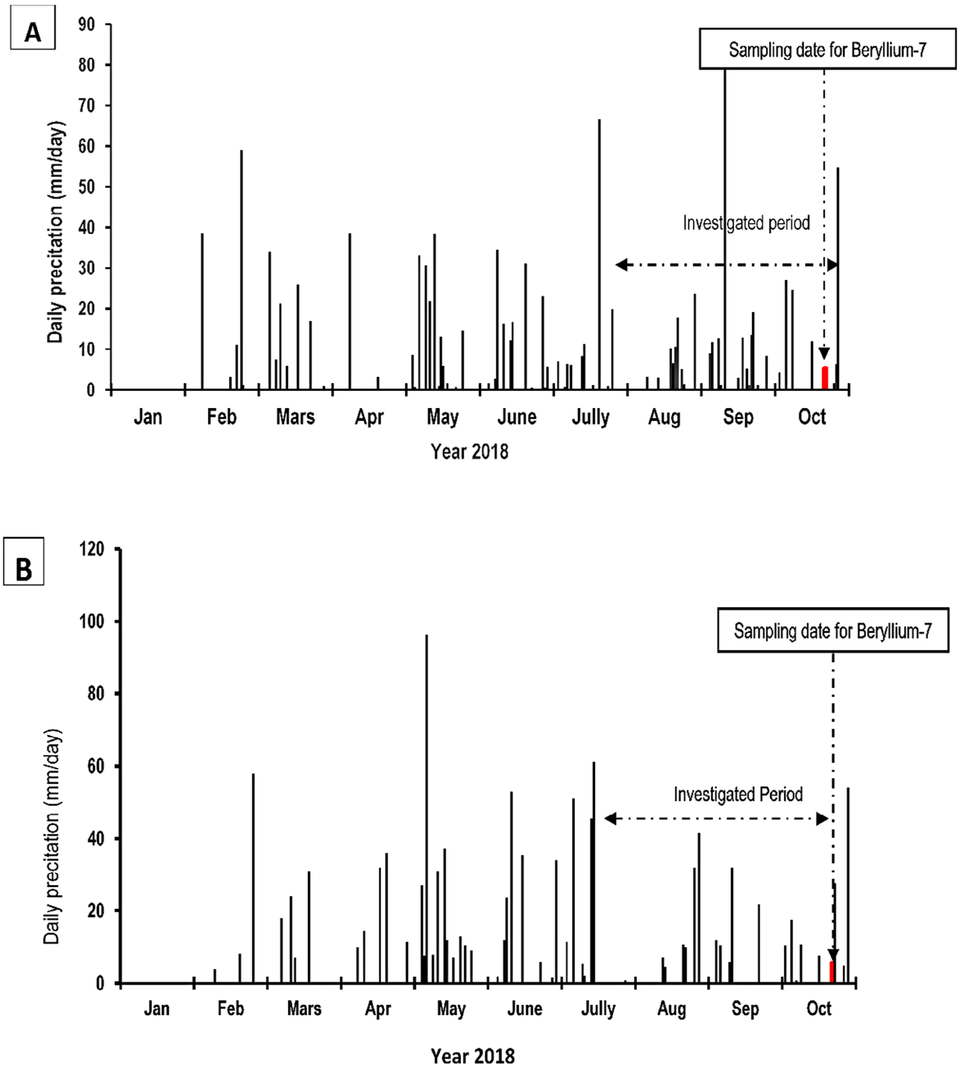

FIGURE 1 The daily precipitation recorded for the study sites ([A] Dan and [B] Za-zounmè) for the period from January 1 to October 31, 2018. The arrow shows the date of soil sampling for beryllium-7 (^{7}Be) measurements (October 21, 2018, at Dan and October 22, 2018, at Za-zounmè).

2.2 | Experimental design

Maize was selected for this experiment because it is commonly grown in this area, and it has low soil conservation efficiency. The planting density was 35,000 seed hills/ha. A random complete block with four replications was used as the experimental design. The treatments combined three tillage practices: no-tillage, slope ridging, and contour ridging and three amounts of mulch: 0 M (0 t ha^{-1}); 3 M (3 t ha^{-1}), and 7 M (7 t ha^{-1}). Thus, the experimental design involved nine treatments (SR0M, SR3M, SR7M, CR0M, CR3M, CR7M, NT0M, NT3M, and NT7M). Maize stover was applied on the soil surface as mulch. The mulch was characterized by a C:N ratio of 47 (%C = 8.23 and %N = 0.17). Being the farmer's practice, SR was used as control in this experiment. The construction of ridges was done manually using hoe and tape measure. The ridges were 60 cm wide and 20 cm high and were oriented from up to down of the slope in the SR plots (Figure 2A) and along the contour lines on CR plots (Figure 2B). On both SR and CR plots, the distances between the ridges were 0.80 cm. On NT, the maize was sowed directly without any soil preparation. The seedlings were placed using a machete.

2.3 | Sediments collection

Runoff plots were used for sediment collection (Akplo et al., 2022; Bashagaluke et al., 2018). Each plot was measured 7 m × 4 m separated from the subsequent plot with metal sheets fixed 0.3 m deep and 0. 5 m of height at the surface to prevent any possible run-off contamination from the neighboring plots (Figure 3). The runoff water and eroded sediment were drained into a storage system composed of two tanks. The first tank was pierced with eight identical holes and connected to the plot with a PVC pipe with 40 mm of diameter. The runoff

FIGURE 2 Slope ridging (A) and contour ridging (B).

and the eroded sediment were exited from seven holes and only from one hole it drained to the second tank.

The total sediment lost (SL) was used to estimate the amount of carbon lost. Total SL was calculated from the dry amount of soil retained in the tanks (direct sediment) and the sediment suspended in the runoff. The measurement was done every time after an erosive rainfall. Direct sediment was collected, air-dried, and weighted. A 500-mL sample was taken from the runoff and oven-dried at 105˚C for 48 h for the suspended sediment quantification. Therefore, the total amount of SL (Q) under each treatment was estimated using Equation (1).

$$Q = Q_1 + Q_2 \tag{1}$$

Q_1 and Q_2 were determined as follows (Equation 2):

$$Q_1 = \frac{b}{a} \times C, \tag{2}$$

where Q_1 is the total dry amount of the direct sediment, a is the fresh weight (g) of the sediment sample, b is the dry weight (g) of the sediment sample, and C is the total fresh weight of the direct sediment.

$$Q_2 = \frac{r_2}{r_1} \times Rf, \tag{3}$$

where Q_2 (g) is the total amount of suspended sediment, r_2 (g) is the mass of dry sediment in the runoff sample, r_1 (mL) is the volume of runoff sample, and Rf (mL) is the total runoff measured on the field.

2.4 | Sediment analysis and carbon loss estimation

A sample of the sediment was ground to pass a 2-mm sieve, bagged, and stored at 4˚C until analysis. Organic carbon content was determined following the modified Nelson and

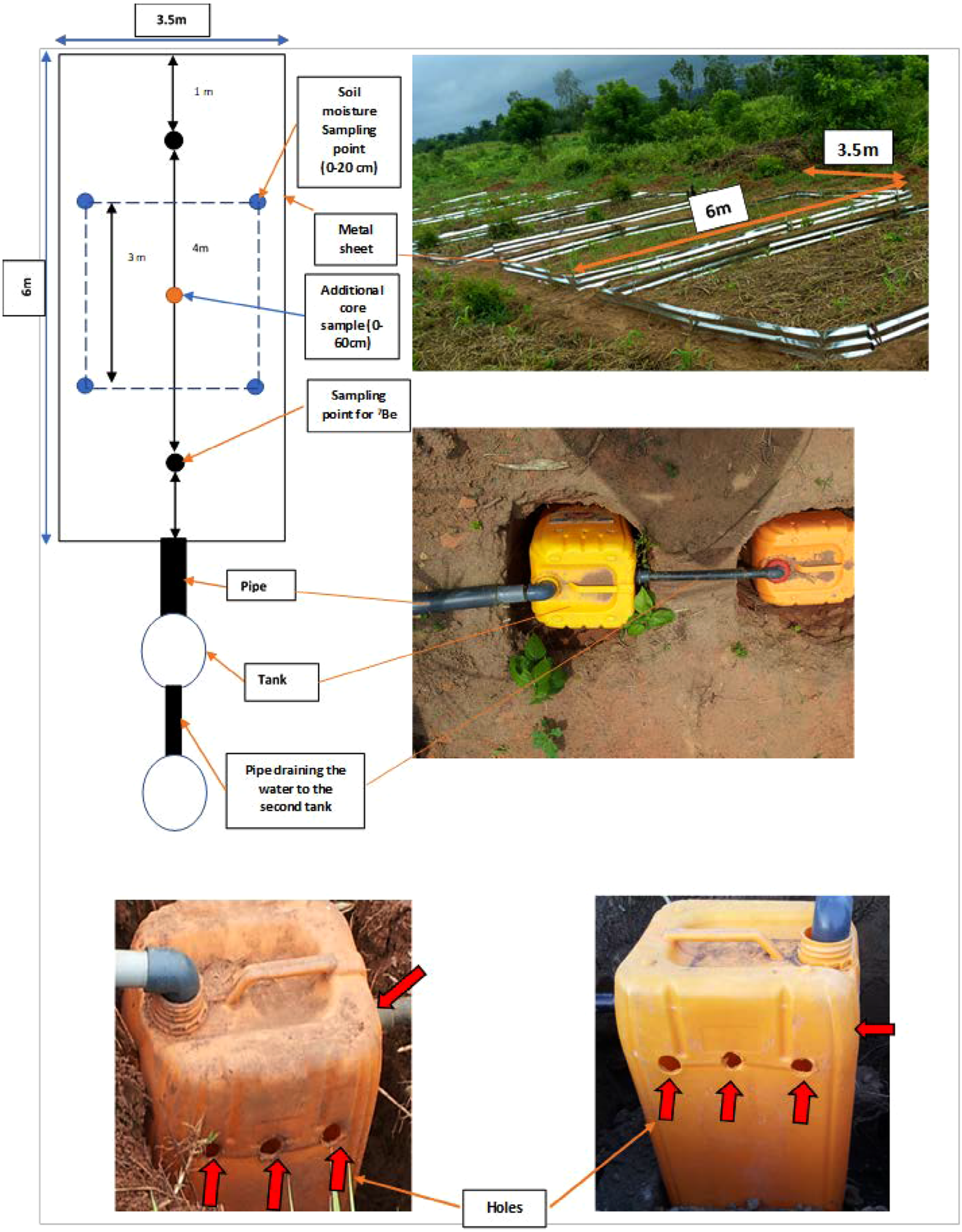

FIGURE 3 The experimental field setup.

Sommers method as outlined in Okalebo et al. (2002). The organic carbon was oxidized by treating the soil with a hot mixture of 5% potassium dichromate ($K_2Cr_2O_7$) and concentrated sulfuric acid (H_2SO_4) at 150°C. After digestion, 0.4% barium chloride (BCl_2) was added to allow cooling. Then, the amount of chromic Cr^{3+} ions formed during the oxidation process was determined by spectrophotometry to give the total amount of organic carbon present in the soil samples. Organic matter fractions of the sediment were isolated using a modified particle size fractionation method and determined using the weight loss on ignition procedure (Cambardella & Elliott, 1992; Gura et al., 2021). Fifty grams of each sediment sample was first dispersed with a solution of Calgon (10% sodium hexametaphosphate—50 g L^{-1}) and passed through a series of nested sieves of sizes 2000, 250, and 53 µm in a wet sieving apparatus. The 53- to 2000-µm fraction was referred to as labile organic matter or particulate organic matter (POM). The particles that passed through the 53-µm fraction was referred to as the stable organic matter or fine organic matter (MOM). The separated particles were washed with de-ionized water until clean and dried at 65˚C for 24 h. The oven-dried sediment particles were heated in a muffle furnace at 450˚C for 4 h to separate the mineral particles from the organic particles. After cooling, the amount of organic matter (OM) was determined as shown in Equation (4).

$$\mathrm{OM}\,(\mathrm{g/g}) = \frac{\text{Weight at } 55^{\circ}\mathrm{C} - \text{Weight at } 450^{\circ}\mathrm{C}}{\text{Weight at } 55^{\circ}\mathrm{C}}. \quad (4)$$

The amount of carbon in each size fraction was estimated using a conversion factor of 1.724, based on the assumption that organic matter contains ∼58% organic carbon (Nelson & Sommers, 1996).

The amount of total or labile or stable organic carbon contained in sediment, CL (g) was computed using Equation (5):

$$\mathrm{CL} = C \times Q, \quad (5)$$

where C (g kg^{-1}) is the content of each of the organic fraction component (total or labile or stable organic carbon) in the sediment, and Q (kg) is the total amount of SL.

2.5 | Soil moisture determination

On each plot, five soil samples were taken from a grid of 3 m × 3 m for soil moisture content determination. The soil samples were taken on 0–10, 10–20, 20–30, 30–40, and 40–50 cm after each erosive rain event. The five soil samples of the same layer were mixed in one composite sample. In other words, one composite of five samples of each layer was used for soil moisture calculation. Soil moisture (H) was determined by the "thermo-gravimetric method'' (Anderson & Ingram, 1993). The wet weight (P_W) of the samples was determined on site, and the dry weight (P_D) was determined in the laboratory after oven drying at 105˚C until a constant dry weight. Soil moisture content (H) was determined as suggested by Anderson and Ingram (1993):

$$H\ (\%) = (P_W - P_D)/P_D \times 100.. \quad (6)$$

2.6 | Sampling strategy for ^{7}Be determination and gamma spectrometry

The present investigation was done during heavy rain period from May 2018 to October 2018. The treatments had been installed since May 28, 2018, at Dan and May 12, 2018, at Za-zounmè. The soil sampling for ^{7}Be was done on October 21, 2018, at Dan and October 22, 2018, at Za-zounmè. Since fallout radionuclides (i.e., ceasium-137, lead-210, and ^{7}Be) were used as soil tracers, the redistribution rate assessment was based on the comparison of the inventory measured at a given sampling site with a reference site. When the inventory value at the study site was lower than that of the value of the reference inventory, it indicated that the study site was affected by erosion and, in the opposite case, by deposition (de Rosas et al., 2018; Sepulveda et al., 2008). In this study, the reference sites were selected at each study site (one reference site was sampled at Dan and one at Za-zounmè). They were localized near the installed treatments (described below) on flat (≈1%) land uncultivated since August 2012 and without evidence of soil redistribution (erosion or sedimentation). Ten cores were taken following a grid approach for the reference inventory estimation (Mabit et al., 2014). As the use of ^{7}Be technique strongly depends on the h_0 parameter, the depth distribution was measured to a depth of 3 cm at a resolution of 3 mm as described by Mabit and Black (2019).

Three soil cores (∅ = 25 cm, h = 3 cm) were sampled at each experimental plot, in its upper and lower part of the plot using a surface cylindrical collector (Figure 2). The sampling points were 4 m apart. The collected samples were bulked to analyze the total inventory of ^{7}Be. On the plots with mulch, the samples of mulch were taken in order to quantify the fraction of ^{7}Be adsorbed by mulch. The ^{7}Be fraction intercepted and adsorbed by the mulch was estimated and subtracted from the initial reference inventory as the reference site was a bare soil. These values were used as reference values depending on the amount of the mulching. However, for the plot without mulching, the initial reference inventory was used as baseline. The collected samples were air-dried, ground hand, and sieved at 2 mm.

^{7}Be was measured by gamma spectrometry using a High Purity Germanium (HPGe) detector, p-type, with a relative efficiency of 45% and energy resolution of 2 keV at 1332 keV. The ^{7}Be activity was determined from the net peak area of gamma ray at 477.6 keV (emission intensity of 10.40%). Energy and efficiency calibrations were performed using a certified multigamma standard source (^{137}Cs, ^{60}Co, ^{57}Co, ^{139}Ce, ^{109}Cd, ^{113}Sn, ^{88}Y, and ^{241}Am). Standard and unknown samples were prepared in the same cylindrical geometry of 100 mL. The efficiency at the energy of 477.6 keV of ^{7}Be was calculated by using the polynomial equation obtained by fitting the efficiency versus energy experimental curve obtained from the analysis of the mutligamma standard source. The counting time for the samples was 24 h to reach a precision of ∼10% at the 95% level of confidence. Due to the short half-life (53.3 days) of ^{7}Be, the activities have been corrected for decay between the collection period and counting time using the following equation (Mabit et al., 2014):

$$\frac{\lambda t}{1 - \exp\left(1 - \lambda t\right)}, \tag{7}$$

where λ is the decay constant, and t is the elapsed time (time variation between the sampling time and the analysis time).

2.7 | Estimation of soil redistribution using ^{7}Be tracer

As explained above, a stable reference site was selected to measure the baseline ^{7}Be inventory, which was compared with the ^{7}Be inventory at the sampling locations. The profile distribution model described by Blake et al. (1999) was used to convert the ^{7}Be inventories into erosion or deposition rate. This model was based on the depth distribution of the radionuclide in the soil column at an undisturbed site. Soil mass depth was used to measure depth in soil and was calculated by dividing the soil mass (kg) by the area of soil layer (m^{2}). The initial depth distribution $C(x)$ of ^{7}Be is commonly exponential (de Rosas et al., 2018; Sepulveda et al., 2008; Taylor et al., 2019; Zhang et al., 2014) and can be expressed as:

$$C\ (x) = C\left(0\right) e^{\left(-\frac{x}{h_0}\right)}, \tag{8}$$

where x is the mass depth from the soil surface (positive downward) (kg m^{-2}), $C(x)$ is the mass activity of ^{7}Be at a depth x (Bq kg^{-1}), C (0) is the mass activity of the surface soil (at $x = 0$ Bq kg^{-1}), and h_0 is the relaxation mass depth (kg m^{-2}) at which 63% of the total ^{7}Be activity was above and was used to quantify ^{7}Be penetration into soil (Ryken et al., 2018; Zhang et al., 2014).

The ^{7}Be reference inventory, A_{ref} (Bq m^{-2}), represented the total areal activity at a reference site within the study area:

$$A\ \ (0) = A_{\mathrm{ref}} = \int_0^{\infty} C\left(x\right) dx = C\left(0\right) h_0. \tag{9}$$

Considering the initial distribution, the areal activity density below mass depth x, $A(x)$ (Bq m^{-2}), is therefore:

$$A\ \ (x) = \int_{-x}^{\infty} C\left(x\right) dx = A_{\mathrm{ref}}\ e^{\left(x/h_0\right)}. \tag{10}$$

The measured ^{7}Be inventory A (Bq m^{-2}) at the specific sampling point reflected the depth of soil lost x (kg m^{-2}, negative) and can be represented as:

$$x\ = h_0\ \ln\left(\frac{A}{A_{\mathrm{ref}}}\right). \tag{11}$$

Deposition of sediment was reflected in an excess of ^{7}Be inventory at the sample site with respect to the reference site. The depth of deposition, x' (kg m^{-2}, positive), was calculated as:

$$x' = \left(A - A_{\mathrm{ref}}\right)/C_d, \tag{12}$$

where C_d (Bq kg^{-1}) is the ^{7}Be concentration of deposited sediment, which may be estimated using the mean ^{7}Be concentration of the sediment eroded from the upslope eroding areas calculated as:

$$C_d = \int_S xC_e\ dS / \int_S x\ dS. \tag{13}$$

The ^{7}Be activity concentration in the eroding sediment at each upslope point, C_e (Bq kg^{-1}), was calculated from the loss of inventory divided by the mass of soil loss:

$$C_e = \left(A_{\mathrm{ref}} - A\right)/x. \tag{14}$$

2.8 | Statistical analysis

A series of statistical analyses were performed. First, multisite mixed-effect analyses of variance models matching the study design were conducted for each of the collected variable; site, tillage system, and mulch input rates effects as fixed effects; and tillage system nested in block nested in site as random effects. This first analysis showed a significant site effect. Given the significant site effect, a three-way analysis of variance (ANOVA) using the PROC MIXED procedure was conducted on each site. Tillage system and mulch input rates were taken as a fixed effect, while block was considered a random effect. Significant fixed effects were further dissected by extracting means and performing Tukey's honestly significant difference pairwise comparisons. The normality and homogeneity of the data for each variable were tested by Shapiro–Wilk test (Shapiro & Wilk, 1965) and by the Bartlett test (Bartlett, 1937), respectively. The relationship between soil erosion and organic carbon loss, fine particle content, soil density, and ^{7}Be activity was analyzed using correlation analysis. All statistical analyses were conducted in R (version 4.2.1) with an alpha of 0.05. Due to interactions between tillage and mulch input rates, the main effects were not reported.

TABLE 2 Effect of studied treatments on soil moisture content of topsoil and runoff (mean ± standard deviation).

Treatments	Soil moisture content (%)		C_POM (kg ha^{-1})		C_MOM (kg ha^{-1})		Total C loss (kg ha^{-1})	
	Dan	Za-Zounmè	Dan	Za-zounmè	Dan	Za-zounmè	Dan	Za-zounmè
CR0M	13.79 ± 0.42d	6.83 ± 0.19c	113.023c	53.58c	275.62bc	130.66 cd	388.64 cd	184.24bc
CR3M	17.48 ± 0.86a	6.99 ± 0.10c	104.50c	69.18c	252.91bc	167.44bcd	357.41 cd	236.63bc
CR7M	17.70 ± 0.60a	12.08 ± 0.19a	103.51c	27.64c	114.20c	48.83d	151.04d	76.48c
NT0M	12.55 ± 0.11e	6.32 ± 0.21c	332.57ab	243.43a	455.98b	333.77abc	788.544b	643.87a
NT3M	13.22 ± 0.55de	6.74 ± 0.31c	168.93bc	252.48a	305.99bc	341.53ab	474.92c	594.02a
NT7M	15.68 ± 0.21bc	6.54 ± 0.1c	73.852c	27.42c	297.02bc	135.97bcd	370.88 cd	183.39c
SR0M	14.98 ± 0.25c	6.25 ± 0.41c	358.78a	200.23b	777.56a	433.95a	1136.35a	634.19a
SR3M	13.73 ± 0.06d	6.4 ± 0.49c	165.24bc	192.75b	821.66a	184.72bcd	986.90ab	377.46b
SR7M	16.29 ± 0.20b	8.55 ± 0.18b	147.15c	59.73c	217.60c	156.82bcd	381.42cd	216.55bc
p-value	<0.0001	0.0043	0.0015	<0.0001	<0.0001	<0.0006	<0.0001	<0.0001

Note: Means with the same letter are not significantly different. NT0M, no tillage + 0 t ha^{-1} of mulch; NT3M, no tillage + 3 t ha^{-1} of mulch; NT7M, no tillage + 7 t ha^{-1} of mulch; SR0M, slope ridging + 0 t ha^{-1}; SR3M, slope ridging + 3 t ha^{-1} of mulch; SR7M, slope ridging + 7 t ha^{-1} of mulch; CR0M, contour ridging + 0 t ha^{-1} of mulch; CR3M, contour ridging + 3 t ha^{-1} of mulch; CR7M, contour ridging + 7 t ha^{-1} of mulch.

3 | RESULTS

3.1 | Organic carbon loss

The amount of SOC loss is significantly ($p < 0.05$) influenced by tillage × mulch interaction on both sites (Table 2). Between the two organic carbon fractions (i.e., C_POM C_MOM), the fine fraction (C_MOM) is the most lost for all treatments on both sites. The observed differences in loss between C_POM and C_MOM ranged from 10.69 to 657 kg/ha at Dan and from −8.03 to 233 kg/ha at Za-zounmè. They were higher for treatments SR0M, SR3M, and NT0M. However, the total amount of carbon lost (total C) varied from 151 (CR7M) to 1136 kg/ha (SR0M) at Dan and from 76.48 kg/ha under the CR7M treatment to over 600 kg/ha NT0M and SR0M at Za-zounmè.

3.2 | Soil moisture distribution

The soil moisture of topsoil was very low at both sites, especially at Za-zounmè (6.3%–12.1%) but also at Dan (12.6%–17.7%). Statistical differences were observed between the treatments at both Dan and Za-zounmè (Table 2). At both sites, the gravimetric soil moisture content was the lowest on the NT0M plots (12.55% at Dan and 6.33% at Za-zounmè) and the highest on the CR7M plots (17.7% at Dan and 12.1 at Za-zounmè). The difference between the extremes was 5.1% at Dan and 5.8% at Za-zounmè.

The examined soil conservation treatments have impact on the soil moisture in the deeper part of the soil profile (below 30 cm). The depth distribution of soil moisture is shown in Figure 4. For all treatments, the moisture in the deeper part of the soil profile (30 cm and more) is considerably higher than in the topsoil. Mulch increases soil moisture for all three tillage treatments, and this effect is well articulated, especially if the amount of mulch is great. The differences between 7 t ha^{-1} of mulch and 3 t ha^{-1} of mulch are usually greater than the differences between 3 t ha^{-1} of mulch and no mulch.

3.3 | ^{7}Be activity on reference and experimental plots

The initial depth distribution of ^{7}Be at the reference sites is shown in Figure 5. For both reference sites, the ^{7}Be activity decreased exponentially with increasing mass depth from the top layer to a depth of 3 cm. However, for the reference site of Dan, the mass depth was found to be higher (43.39 kg m^{-2}) than at Za-zounmè (29.62 kg m^{-2}). At both reference sites, 63% of the total areal activity was found in the soil above a mass depth of 5 kg m^{-2} (h_0 = 5.75 at Dan and h_0 = 5.46 at Za-zounmè), that is, the upper 3 mm. We found initial ^{7}Be concentration C (0) of 55.58 and 78.51 Bq kg^{-1} at Za-zounmè and Dan, respectively, corresponding to an areal activity of 302 and 451 Bq m^{-2} (Table 3). Owing to uncertainties from sampling, the gamma spectrometry measurements, and the curve fitting, the inventory (As) obtained by summing the ^{7}Be areal activity of the depth incremental samples collected from the reference site was different from that derived by integrating the area above the fitted curve [$A(0)$] at Dan (Table 4). The measured ^{7}Be inventory of the whole core sampled at reference site was 313.65 ± 50 Bq m^{-2} for Za-zounmè and 392.78 ± 37 Bq m^{-2} for Dan. As explained above, the ^{7}Be fraction intercepted and adsorbed by the mulch was considered (Table 3), and it was found that this fraction ranges from

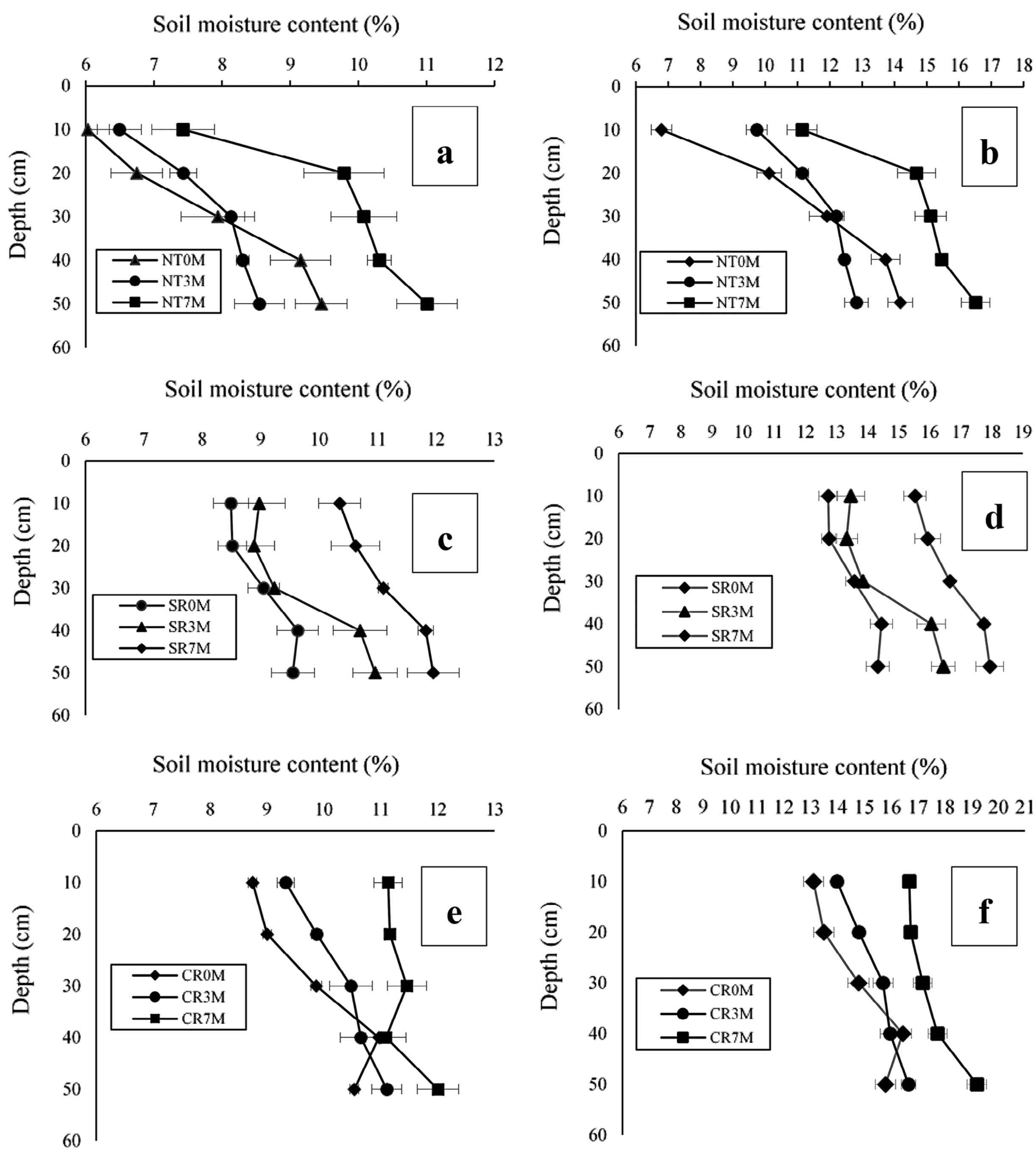

FIGURE 4 Effect of tillage and mulching on the depth distribution of soil moisture: (A) no-tillage treatments at Za-zounmè; (B) no-tillage treatments at Dan; (C) slope ridging at Za-zounmè; (D) slope ridging at Dan; (E) contour ridging at Za-zounmè; and (F) contour ridging at Dan. The error bars represent the standard deviation for each treatment. NT0M, no tillage + 0 t ha^{-1} of mulch; NT3M, no tillage + 3 t ha^{-1} of mulch; NT7M, no tillage + 7 t ha^{-1} of mulch; SR0M, slope ridging + 0 t ha^{-1}; SR3M, slope ridging + 3 t ha^{-1} of mulch; SR7M, slope ridging + 7 t ha^{-1} of mulch; CR0M, contour ridging + 0 t ha^{-1} of mulch; CR3M, contour ridging + 3 t ha^{-1} of mulch; CR7M, contour ridging + 7 t ha^{-1} of mulch.

TABLE 3 Expression of the initial beryllium-7 (^{7}Be) distribution (the uncertainties represent the standard deviation).

Site	Mass activity distribution	Areal activity distribution	h_0 (Bq m^{-2})	Am (Bq m^{-2})	A (0) (Bq m^{-2})	$A_{initial}$ (Bq m^{-2})
Za-zounmè	55.58 exp ($-x$/0.183)	302 exp ($-x$/0.183)	5.46	304.77 ± 57	302.05	313.65 ± 50
Dan	78.51 exp ($-x$/0.174)	451 exp ($-x$/0.174)	5.75	393.75 ± 88	451.21	392.78 ± 7

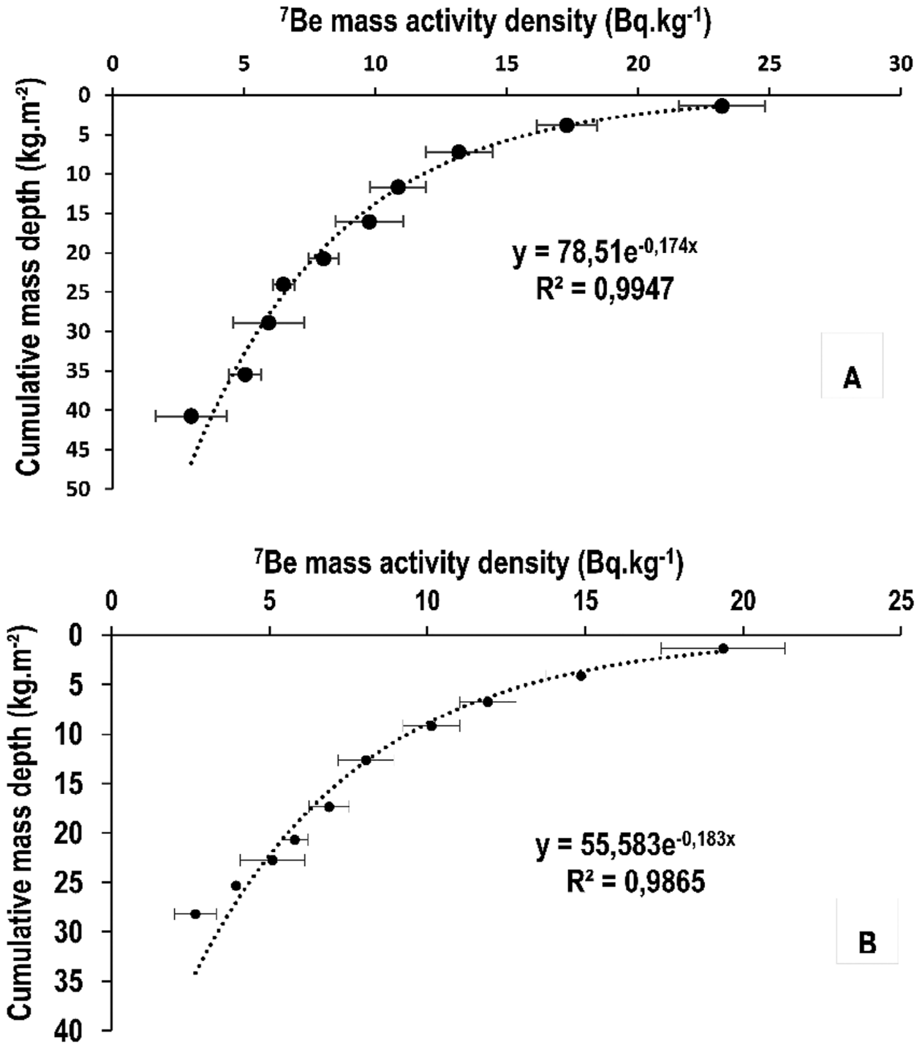

FIGURE 5 The depth distribution of beryllium-7 (^{7}Be) mass activity: (A) at Dan and (B) at Za-zounmè. The error bars represent the precision of gamma spectrometry measurements at the 95% confidence level.

TABLE 4 Beryllium-7 (^{7}Be) reference inventory for each plot (the uncertainties represent the standard deviation).

Site	Mulch amount (t ha^{-1})	$A_{initial}$ (Bq m^{-2})	A_{uptake} (Bq m^{-2})	% Relative to no mulch	A_{used} (Bq m^{-2})
Za-zounmè	0	313.65 ± 50.44	0	0	313.65 ± 50.44
	3	313.65 ± 50.44	23.33 ± 1	6	290.32 ± 0.99
	7	313.65 ± 50.44	58.55 ± 3.65	16	255.10 ± 3.63
Dan	0	392.78 ± 7.65	0	0	392.78 ± 7.65
	3	392.78 ± 7.65	15.65 ± 0.23	4	377.12 ± 23.00
	7	392.78 ± 7.65	39.87 ± 1.23	10	352.91 ± 12.3

4% (for 3 t ha^{-1} of mulch) to 16% (for 7 t ha^{-1} of mulch). By subtracting the ^{7}Be uptake by the mulch, the initial amount of ^{7}Be received by the soil (A_{used}) under each treatment was calculated (Table 4). At Dan, the inventory values used as reference are 392.78 Bq m^{-2} for the 0 M plots, 377.12 Bq m^{-2} for the 3 M plots, and 352.91 Bq m^{-2} for the 7 M plots, and at Za-zounmè, it was 313.65 Bq m^{-2} for the 0 M plots, 290.32 Bq m^{-2} for the 3 M plots, and 255.10 Bq m^{-2} for the 7 M plots.

The ^{7}Be inventories (Bq m^{-2}) associated with the treatments are shown in Figure 6. The observed levels range from 323.75 to 411.37 50 Bq m^{-2} with an average of 362.89 ± 30.50 Bq m^{-2} at Dan, and from 303.39 to 390.62 Bq

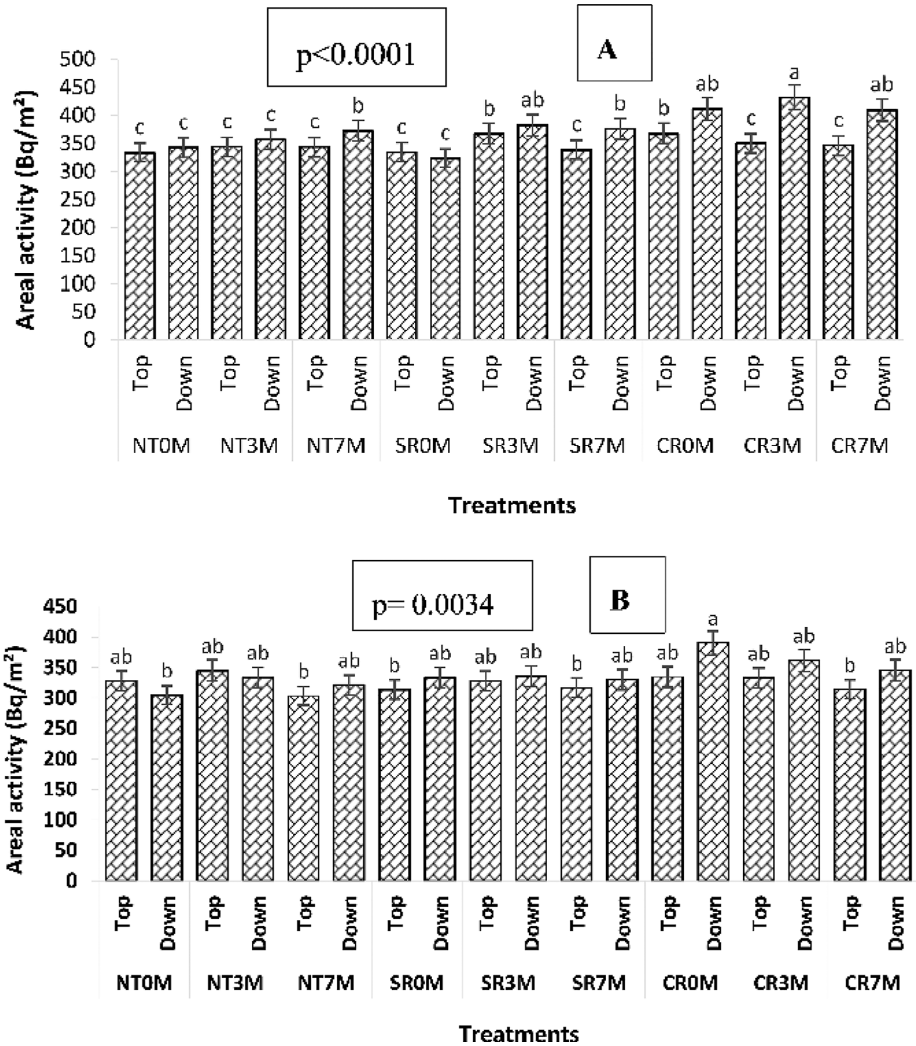

FIGURE 6 Inventories of beryllium-7 (^{7}Be) in soil at (A) at Dan and (B) at Za-zounmè. Means with the same letter are not significantly different. NT0M, no tillage + 0 t ha^{-1} of mulch; NT3M, no tillage + 3 t ha^{-1} of mulch; NT7M, no tillage + 7 t ha^{-1} of mulch; SR0M, slope ridging + 0 t ha^{-1}; SR3M, slope ridging + 3 t ha^{-1} of mulch; SR7M, slope ridging + 7 t ha^{-1} of mulch; CR0M, contour ridging + 0 t ha^{-1} of mulch; CR3M, contour ridging + 3 t ha^{-1} of mulch; and CR7M, contour ridging + 7 t ha^{-1} of mulch.

m^{-2} with an average of 331.77 ± 20.74 Bq m^{-2} at Za-zounmè. As explained above, two samples were taken at each experimental plot (in the upper and lower parts of the plot). The ^{7}Be inventories at the upper slope positions on all plots are lower than the reference values. At the lower slope position, the ^{7}Be inventories are higher than the reference inventory for NT7M, SR3M, CR0M, CR3M, and CR7M at Dan (Figure 5A) and SR7M, CR3M, and CR7M at Za-zounmè (Figure 5B). However, at Dan, the mean inventory of ^{7}Be on the treatments NT0M, NT3M, SR0M, SR3M, and CR0M was lower than the reference inventory indicating net soil loss, while for NT7M, SR7M, CR3M, and CR7M, it was higher, thus indicating deposition. At Za-zounmè, the mean inventory of ^{7}Be on the treatments NT0M, NT3M, NT7M, SR0M, SR3M, IR0M, and IR3M was lower inventory but for SR7M and CR7M, it was higher than the reference inventory.

3.4 | Soil redistribution

Based on the ANOVA, soil redistribution was significantly affected (p < 0.0001) by the tillage × mulch interaction, and the impact was different between the study sites. Mulch decreased soil erosion for all three tillage practices, and this effect is pronounced especially if the amount of mulch is great. On the other hand, it was observed that CR was more efficient in soil erosion control than NT and SR.

Overall, tillage practices combined with 0 t ha^{-1} mulch were associated with higher soil erosion (Table 5). More than 5 t ha^{-1} of soil erosion were recorded under SR + 0 t ha^{-1} of mulch (SR0M) and NT + 0 t ha^{-1} of mulch (NT0M) at both sites. Contour ridging + 0 t ha^{-1} of mulch (CR0M) also led to soil erosion (−0.76 t ha^{-1} Dan and −2.90 t ha^{-1} at Za-zounmè), but the value was low compared with SR0M and

TABLE 5 Soil redistribution under tillage × mulching interaction (negative values indicate soil erosion and positive values indicate deposition).

Tillage × Mulch	Soil redistribution (t ha^{-1})	
	Dan	Za-zounmè
CR0M	−0.76b	−2.89de
CR3M	1.07b	−1.58d
CR7M	4.055a	3.93a
NT0M	−8.63d	−7.37 g
NT3M	−4.195c	−2.80de
NT7M	0.805b	1.69b
SR0M	−10.19d	−6.13fg
SR3M	−0.38b	−4.03e
SR7M	1.35b	0.24c
p-value	<0.0001	<0.0001

Note: Means with the same letter are not significantly different. NT0M, no tillage + 0 t ha^{-1} of mulch; NT3M, no tillage + 3 t ha^{-1} of mulch; NT7M, no tillage + 7 t ha^{-1} of mulch; SR0M, slope ridging + 0 t ha^{-1}; SR3M, slope ridging + 3 t ha^{-1} of mulch; SR7M, slope ridging + 7 t ha^{-1} of mulch; CR0M, contour ridging + 0 t ha^{-1} of mulch; CR3M, contour ridging + 3 t ha^{-1} of mulch; CR7M, contour ridging + 7 t ha^{-1} of mulch.

NT0M. For all three tillage practices, applying 3 t ha^{-1} significantly reduced soil erosion by 60%–80% compared with the treatments without mulch (i.e., NT0M, SR0M, and CR0M), and CR3M resulted in soil deposition at Dan. However, no-tillage + 7 t ha^{-1} of mulch (NT7M), SR + 7 t ha^{-1} of mulch (SR7M), and Contour ridging + 7 t ha^{-1} of mulch (CR7M) led to soil deposition instead of erosion on both sites. The soil deposition ranged between 0.9 t ha^{-1} (SR7M) and 4.05 t ha^{-1} (CR7M) at Dan and between 0.24 t ha^{-1} (SR7M) and 3.93 t ha^{-1} (CR7M).

3.5 | Relationship between soil erosion and organic carbon loss, fine particle content, soil density, and ^{7}Be activity

Figure 7 shows the relationship between erosion rate and organic carbon loss, fine particle content, soil density, and ^{7}Be activity in both sites. A positive and significant correlation was observed between the soil erosion and the loss of organic carbon fractions (C_MOM, C_POM, and total C) as well as the proportion of fine particles (clay and silt). In fact, an increase in the soil lost is associated with an increase in organic carbon and fine soil loss particles, and when erosion increased by one unit, the loss of C_POM, C_MOM, total C, and fine particle increased by 0.74, 0.70, 0.78, and 0.72 respectively. The correlation between soil loss and ^{7}Be activity and soil bulk density was negative but not significant.

4 | DISCUSSION

4.1 | Soil moisture

The results showed a significative effect of the tillage × mulch interaction on both sites on soil moisture in the topsoil. At both sites, soil moisture of the topsoil was higher in the CR plots compared to the NT and SR plots. It also increased as mulch rates increased for each tillage practice. In fact, CR3M and CR7M showed greater soil moisture. CR3M and CR7M treatments combine the benefits of CR and mulching. CR limits runoff, while mulching limits evaporation. It has been shown that mulching can reduce soil water evaporation by 10%–50% (Douzet et al., 2010; Houngnandan et al., 2018; Mazarei & Ahangar, 2013). The impact of tillage × mulch interaction is detectable also in deeper layers, although the impact is lower in deeper layers than in the topsoil layers. In the two sites, the soil moisture difference between the topsoil and deeper layers was high in NT0M treatment. However, in this treatment, the soil moisture in the topsoil was lower than the NT3M treatment (as it is for all tillage treatments) in the deeper layers which had higher soil moisture than NT3M treatment. This can be explained by the occurrence of continuous vertical macropores which are known to develop under NT treatment (Sun et al., 2020). These macropores significantly increase soil permeability and help to drain rainfall to a deeper part of the soil profile (He et al., 2009). Mulch on soil surface results in ponding, and the interception of raindrop thus hinders quick infiltration. This could probably cause the difference between soil moisture of topsoil and subsoil under NT treatment without mulch and NT treatment with mulch than what is between soils under CR and SR.

4.2 | Soil carbon loss through soil erosion

The evaluation of carbon loss showed that the fine organic fraction that is associated with silt-clay (<53 µm) is more eroded than the coarse fraction. In other words, the carbon of the fine organic matter (C_MOM) is more sensitive to water erosion than that of the particulate organic matter (C_POM). This could be due to the fact that C_MOM has a higher contribution to the total carbon reserve. In addition, due to its small size, it is preferentially eroded with fine soil particles such as clay and silt. Our results corroborate those of Ahoglé et al. (2022) who showed that fine non-particulate organic carbon fraction held the largest contribution to the total organic carbon. Akplo et al. (2017) showed that erosion is a selective process and that fine soil particles such as clay and silt are eroded preferentially. We showed that total carbon loss, C_MOM loss, and C_POM loss are significantly influenced by tillage and mulching at both sites where the use of large amounts of mulch (3–7 kg ha^{-1} mulch) is effective

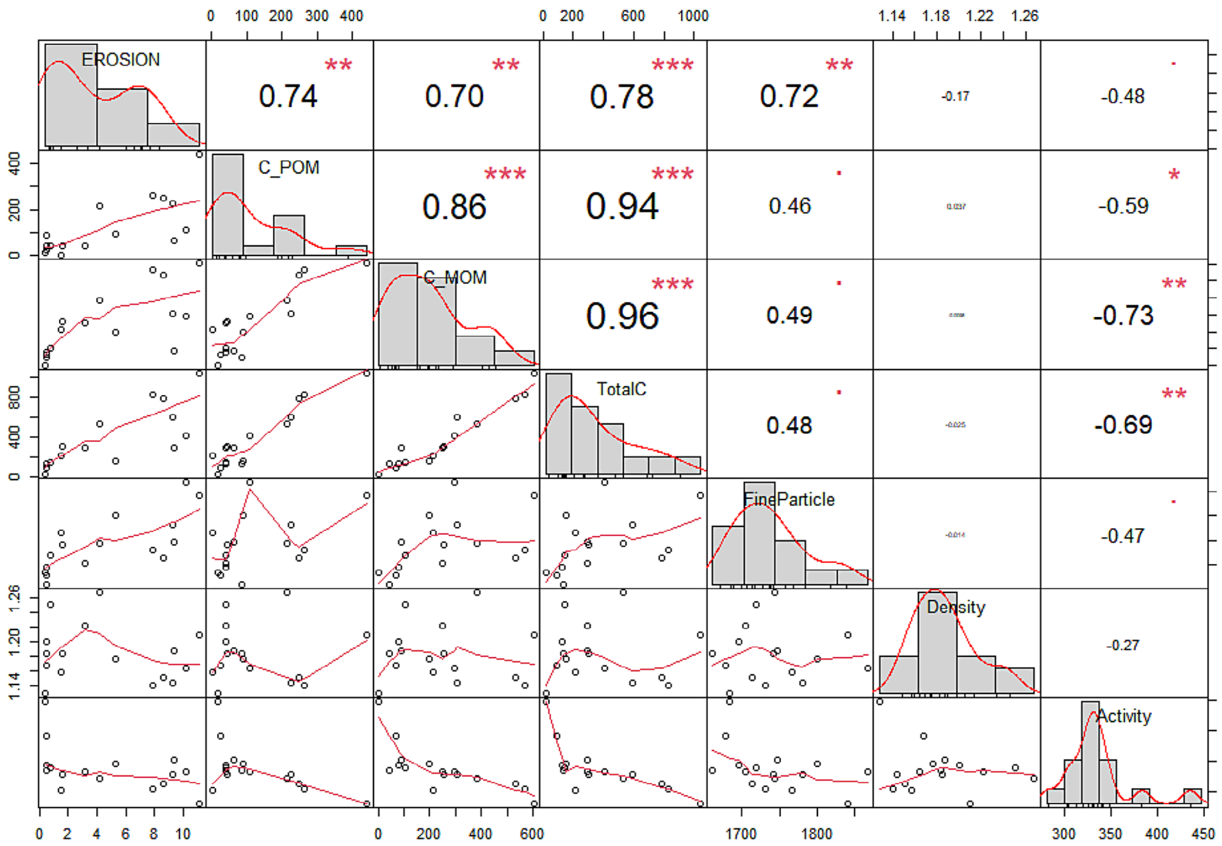

FIGURE 7 Correlation chart between soil erosion and organic carbon loss, fine particle content, soil density, and beryllium-7 (^{7}Be) activity. Erosion, soil erosion; C_POM, carbon of the particulate organic matter; C_MOM, carbon of the fine organic matter; fine particle, percentage of fine particle (clay and silt); density, soil bulk density; activity, ^{7}Be activity.

in reducing carbon loss. Contour ridging reduced carbon loss compared to NT and SR. It has been shown that cropping systems and farm management practices have a great impact on SOC (Croft et al., 2012; Poffenbarger et al., 2017). Tillage induces soil aggregate breakdown and accelerates organic carbon mineralization. Furthermore, the soil organic matter is therefore susceptible to being streamed away during storm rain (Ahoglé et al., 2022). Vegetal mulch protects soil from the raindrop impact (i.e., splash) and therefore reduces soil erosion, nutrient loss, and organic matter loss (Akplo et al., 2022; Bashagaluke et al., 2019).

4.3 | Berylium-7 activity and soil redistribution

In both reference sites, the initial ^{7}Be depth distribution exhibited an exponential shape, with the relaxation mass being around 5 kg m^{-2}. ^{7}Be depth distribution shape observed is similar to other studies reporting an exponential decrease of ^{7}Be and ^{137}Cs in the soil profile (Blake et al., 1999; de Rosas et al., 2018; Meliho et al., 2019). For the reference sites, the mean values of ^{7}Be are found about 313.65 Bq m^{-2} in Za-zounmè and 392.78 Bq m^{-2} in Dan. The reference value is higher at Dan than Za-zounmè. This can be explained by the difference in rainfall. For the investigated period (from September to October 2018), it was recorded to be 321.26 mm at Dan, while it was 220 mm at Za-zounmè. The correlation between the ^{7}Be fall and rainfall was widely assumed. Wallbrink and Murray (1994) and Short et al. (2007) stated that ^{7}Be concentration is correlated to the amount of rainfall received. The coefficient of variation obtained is lower than 30%. This indicates that the reference selected meets the requirements to be used as a reference site (Mabit & Blake, 2019). The reference value closed to the reference value of 473 Bq m^{-2} was found by Sepulveda et al. (2008), and the reference value of 350 Bq m^{-2} was found by de Rosas et al. (2018).

The data showed that CR was associated with low soil erosion, whereas NT and SR were associated with high erosion. In the CR system, ridges pose as obstacles to runoff by reducing water velocity, thus maintaining it onsite. This effect is due to the fact that they are built following the contour lines. Thus, these facilitate water infiltration and the deposition of detached soil particles, thus enhancing the retention of soil sediments in the field. Contrary to CR, the ridges are oriented in the direction of slope in the SR system. The furrow serves as a means for directing runoff water, leading to high soil erosion. A growing body of research over the past few years has shown that CR can significantly curb water erosion compared with SR (Akplo et al., 2022; Barton et al., 2004; Shi et al., 2004; Stevens et al., 2009). The review of the literature on NT or minimum tillage suggests that they typically result in a significant reduction in surface runoff and sediment losses (Quinton & Catt, 2004; Ryken et al., 2018; Silgram & Shepherd, 1999; Strauss et al., 2003). However, our results showed that NT without mulch was not effective in erosion control compared to CR and SR. High soil erosion may have been observed under NT in this study because it was implemented immediately prior to this study. Generally, NT needs a transition phase of 7–8 years (on average) characterized by high soil erosion (Pagnani et al., 2019). Furthermore, the CR practice produced less soil erosion compared to NT due to the substantial size of the ridges (60 cm wide and 20 cm high) formed through manual labor with a hoe. Consequently, the ridges contained an abundance of large macropores causing the soil to be loose and the surface roughness to be high in both ridges and furrows. Therefore, given the loose consistency and significant surface roughness of the CR plot, and the smooth slope of the NT plots, it can be inferred that there was primarily infiltration into the ridges and stagnation in depressions in furrows. As a result, only small amounts of runoff and subsequent soil erosion were generated. Mulching reduced soil erosion across all three tillage practices, with a more significant impact observed when using a larger amount of mulch. Applying 3 t ha^{-1} of mulch reduced by 60%–80% soil erosion, and combining 7 t ha^{-1} of mulch with NT, CR, and SR resulted in deposition. This means that to have real benefit from mulch, a great quantity should be applied, and 7 t ha^{-1} of mulch is effective in soil erosion control under the agroclimatic conditions of Benin. The positive effect of mulch on soil and water conservation is widely documented (Kurothe et al., 2014; Roger-Estrade et al., 2011; Uwizeyimana et al., 2018). The role of surface mulch in soil erosion control is based on reducing the erosive power of falling raindrops and reducing the volume and velocity of runoff (Guto et al., 2012). Mulching is widely considered to have a positive effect on erosion, but this effect depends on the amount of mulch used. Mupangwa et al. (2007) suggested at least 4 t 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 particles detachment by runoff.

The results showed a positive and significant correlation between the soil erosion and the loss of organic carbon fractions (C_MOM, C_POM, and total C) as well as the proportion of fine particles (clay and silt). In other words, an increase in soil erosion was associated with an increase in C_POM, C_MOM, total C, and fine particle loss. As a result, continuous soil erosion can significantly reduce SOC. This consequence of erosion has been widely reported. In Benin, 50%–60% of soils are severely degraded, and this degradation is largely attributed to water erosion (Azontondé et al., 2016).

5 | CONCLUSION

Tillage and mulching significantly affected soil erosion, soil moisture, and carbon fractions loss. The study demonstrated that greater mulch amount associated with CR, SR, or NT reduced soil erosion while increased soil moisture. Furthermore, the application of 3 t ha^{-1} of mulch significantly decreased soil erosion by 60%–80% in comparison to plots without mulch. It was observed that NT + 7 t ha^{-1} of mulch (NT7M), SR + 7 t ha^{-1} of mulch (SR7M), and CR + 7 t ha^{-1} of mulch (CR7M) resulted in soil deposition instead of erosion. Between the two organic carbon fractions, the fine fraction (C_MOM) is the most lost for all treatments on both sites. These findings suggest that in the short term, CR + 3 t ha^{-1} of mulch (CR3M), CR + 7 t ha^{-1} of mulch (CR7M), and SR + 7 t ha^{-1} of mulch (SR7M) can be adopted for water erosion controlling and water conservation. In the long term, it would be preferable if farmers would adopt NT practice because of its long-term sustainable positive impact on soil erosion and its subsequent nutrients loss. Farmers should retain in situ maize residues or other residues of the previous crops and the sow of the next crop without turning the soil by tillage. Land managers and decision makers should offer technical assistance and training to farmers for using soil conservation agricultural practices. Due to the highly variable rainfall and erosion temporal dynamics and spatial distribution, as well as the site-specific effects of soil conservation practices, further research should be conducted to assess the long-term impacts of CR and NT on soil erosion in Benin.

AUTHOR CONTRIBUTIONS

Tobi Moriaque Akplo: Conceptualization; data curation; formal analysis; investigation; methodology; visualization; writing—original draft; writing—review and editing. **Felix Kouelo Alladassi**: Conceptualization; data curation; investigation; methodology; writing—review and editing. **Mahougnon Charlotte Carmelle Zoundji**: Methodology; visualization; writing—review and editing. **Emil Fulajtar**: Conceptualization; funding acquisition; project administration; supervision; validation; writing—review and editing. **Moncef Benmansour**: Conceptualization; funding acquisition; methodology; project administration; validation; writing—review and editing. **Naivo Rabesiranana**: Conceptualization; methodology; project administration; validation; writing—review and editing. **Mathiew Akinseye Folorunso**:

Validation; writing—review and editing. **Pascal Houngnandan**: Conceptualization; funding acquisition; project administration; validation; writing—review and editing.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

ORCID

Tobi Moriaque Akplo https://orcid.org/0000-0002-5668-7855
Félix Kouelo Alladassi https://orcid.org/0000-0002-3831-4756
Mahougnon Charlotte Carmelle Zoundji https://orcid.org/0000-0002-1789-013X
Emil Fulajtar https://orcid.org/0000-0001-5803-9790
Moncef Benmansour https://orcid.org/0009-0004-4591-791X
Naïvo Rabesiranana https://orcid.org/0000-0003-0131-9016
Folorunso Mathew Akinseye https://orcid.org/0000-0002-8677-6306

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