Assessing impact of tillage and mulch on soil erosion estimated by Beryllium-7 and on soil moisture, and runoff in Central Benin

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Abstract

This study was conducted to assess effect of tillage and mulch on soil erosion control in typical agroecological conditions of Benin. In addition, it involved also the assessment of soil moisture and runoff. The experiment was conducted on two sites in Central Benin during the short rain season of 2018. The effect of three tillage practices (contour ridging: CR; slope ridging: SR and no-tillage: NT) and three mulch doses (0 t.ha-1; 3 t.ha-1; and 7 t.ha-1) on soil erosion under maize was investigated at small experimental plots (21 m2). The 7Be method was used to assess the erosion rates, runoff was measured by total collection and soil moisture content was determined by thermo-gravimetric method. The results showed a significant decrease in runoff coefficient and soil loss while increase soil moisture under no-tillage and contour ridges compared to slope ridges. This effect was pronounced with greatest. 3 and 7 tha-1. Highest runoff coefficient and soil loss and the lowest soil moisture were observed under slope ridging without mulch (i.e. SR0M). The 7Be measurement showed high soil losses under SR0M (-10.19 t ha-1) at Dan and under NT0M (-7.36 t ha-1) at Za-zounmè. The treatments NT7M (0.80 t ha-1); SR7M (0.69 t ha-1); IR3M (2.07 t ha-1) and CR7M (4.05 t ha-1) showed deposition at Dan while SR7M (0.23 t ha-1) and CR7M (3.93 t ha-1) showed deposition at Za-zounmè. This study revealed useful information to be taken into consideration when developing soil and water conservation management strategies in Benin.

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Core Ideas

As part of the submission process, we ask authors to prepare highlights of their article. The highlights will consist of 3 to 5 bullet points that convey the core findings of the article and emphasize the novel aspects and impacts of the research on scientific progress and environmental problem solving.

The purpose of these highlights is to give a concise summary that will be helpful in assessing the suitability of the manuscript for publication in the journal and for selecting appropriate reviewers. If the article is accepted the highlights may also be used for promoting and publicizing the research.

Core Idea 1: First application of fallout radionuclides in assessing Short-term soil erosion in Benin.

Core Idea 2: Application of Beryllium-7 provide accurate information on the effects of land management on soil erosion rates

Core Idea 3: No-tillage and Contour ridging reduced erosion and increased soil moisture as compared to slope ridging

Core Idea 4: To have real benefit from mulch, a 3-7 t/ha should be applied.

Core Idea 5: CUST_CORE_IDEA_5 :No data available.

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Keywords: Soil conservation, Conservation tillage; Berillyum-7; Soil redistribution patterns; Benin

1. Introduction

Soil erosion is by far the most important soil degradation process and eroded soils represent approximately 84% of degraded areas worldwide (FAO, 2015). A growing body of research over the last years has shown that soil erosion is one of the most important challenges facing humanity (FAO, 2015; Panagos et al., 2016; Alewell et al., 2019). Oldeman et al (1991) estimated that 56% of the world's soils were under the threat of mild to severe forms of water erosion. However, more than 75% of degraded land is located in the developing countries (Mabit et al., 2014). In Africa, many agricultural regions are affected by water erosion (Bossa, 2007; Bashagaluke et al., 2018). In Benin forest destruction, land over-exploitation and unsuitable agricultural practices have contributed to great changes in the agricultural systems. These changes have led to accentuated soil degradation. As a result, most of the agroecological zones in Benin are characterized by high levels of erosion risk. In Centre Benin, the situation is very worrying. Rainfall comes in the form of localized and violent thunderstorms, on bare soil and run-off is instantly causing soil erosion of the soil surface. This results in declining soil fertility and decreasing crop yields (Saïdou et al., 2012). Cereal crops (e.g. maize) that are strategic in maintaining food security for local populations are highly impacted (Akplo et al., 2022). Maintaining food security in Benin urgently requires a soil conservation strategy to minimize soil erosion. This is all the more urgent considering the fact that the quantity and quality of agricultural production is highly dependent on soil quality (World Economic Forum, 2010).

Conservation Agriculture (CA) practices are considered as an alternative to traditional agricultural practices for ensuring food security and reducing agricultural related soil degradation (Badgley et al., 2007; Farooq & Siddique, 2015). CA is a set of practices, including minimum soil disturbance, permanent soil cover, diversified crop rotations, and integrated weed management (Hobbs et al. 2008; Friedrich et al. 2012). Reducing and/or reverting soil erosion (Van den Putte et al., 2010), soil organic matter (SOM) decline, water loss, soil physical degradation, and fuel use (Baker et al., 2002) and improvement of crops yield and soil biodiversity (Friedrich et al., 2012) are among the well-known effects of CA. CA promotes minimal soil disturbance through no-tillage or reduced tillage, crop residue management and organic wastes; all aimed at reducing soil erosion (Farooq & Siddique, 2015). In Benin, the contour ridging (CR); slope ridging (SR) are the most common tillage practices (Akplo et al., 2019).

The ridges are formed manually using hoe and tape measure and they are 60 cm wide and 20 cm high. The ridges are oriented in slope direction in the case of SR system or along the contour lines in the case of CR system. No-tillage (NT) and mulching practices have been promoted but their adoption by farmers remains very rare. Reduction of runoff and erosion and increase of soil organic carbon (SOC) content, root length and density and soil water storage are the main outcomes of NT practices (Lal, 2004; Fiorini et al., 2018). 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 the specific physical context of centre Benin, certain NT and mulching practices can be useful to address 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). Small traditional farmers are very conservative. They rely on approaches inherited from past and firmly fixed in their traditional way of life (Akplo et al., 2022). Therefore, providing information on the effective soil erosion control practices in Benin is the most important stage for soil conservation.

Erosion plots can provide valuable information regarding on-site erosion rates associated with different soil types or crops and different tillage systems, but they are unable to provide the spatially distributed information required to investigate patterns of soil redistribution within individual fields or on the slopes of a small watershed. However, most developing countries do not have the resources to establish institutionalized land care/watershed development programs for implementing long-term soil conservation activities. The quest for alternative techniques of soil erosion assessment to complement existing methods and to 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 (Zapata, 2002; Walling, 2006; Mabit et al., 2008; Porto et al., 2012; Dercon et al., 2012; Benmansour et al., 2013; Gaspar & Navas, 2013). 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 a potential to quantify the effects of land use and land management on soil erosion rates and to evaluate the efficiency of soil conservation measures. Further it is able to evaluate micro-spatial variation in erosion at the field scale (Mabit et al., 2008; Schuller et al., 2006; Ryken et al., 2018; Mabit & Blake, 2019).

The primary objective of the study was to assess the impact of different tillage practices and different mulch doses on soil erosion (estimated by Beryllium-7), runoff (measured by total collection at experimental plots) and soil moisture content (measured by thermo-gravimetric method) in agroecological conditions typical for Central 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 runoff, and increase soil moisture content.

2. Material and methods

2.1. Study area and experiment period

Two experimental fields were selected: Dan (7°21'35" N; 002°05'09" E) and Za-zounmè (7°12'50" N; 002°15'40" E) (Figure 1). The experimental fields were the same as described in Akplo et al. (2022). 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 (Akplo et al., 2022). The soil of Dan is classified as Acrisol and the soil of Za-zounmè is classified as Ferralsol (IUSS Working Group WRB, 2015). Both sites have similar climate and soil conditions. The sites are situated on gently undulating denudation plateau (the slope inclination is 5% at Dan and 4.6% at Za-zounmè). 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 of 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 average rainfall varies from 1100 to 1300 mm/year and with a bimodal pattern of rainfall distribution for both sites. The rainfall record for the period between January 1 and October 31, 2018 is shown in Figure 2. 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. For this period 321.3 mm were recorded in 29 rain events at Dan and 220 mm were recorded in 16 rain events at Za-zounmè. The targeted period of the present study was September to October.

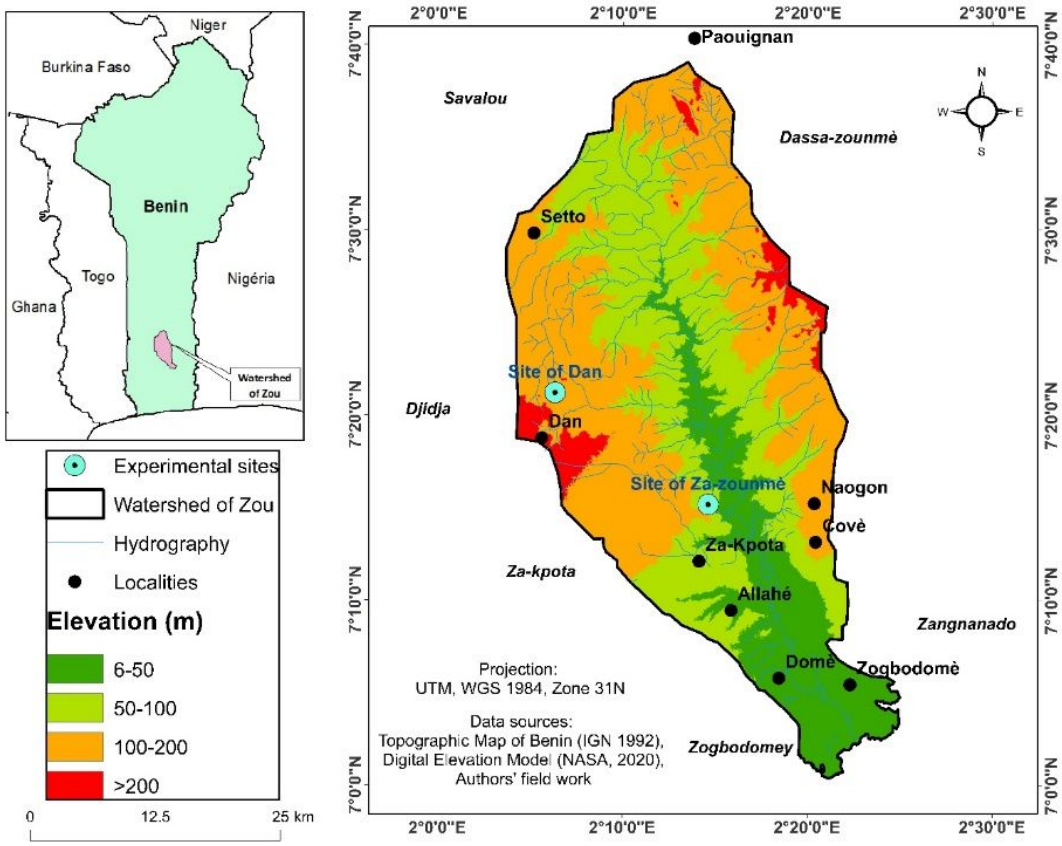


Figure 1: Watershed of Zou and experimental field location [Projection: UTM WGS 1984 Zone 31N; Data source: Topographic Map of Benin (IGN 1992), Digital Elevation Map (NASA 2020), Authors' fieldwork]

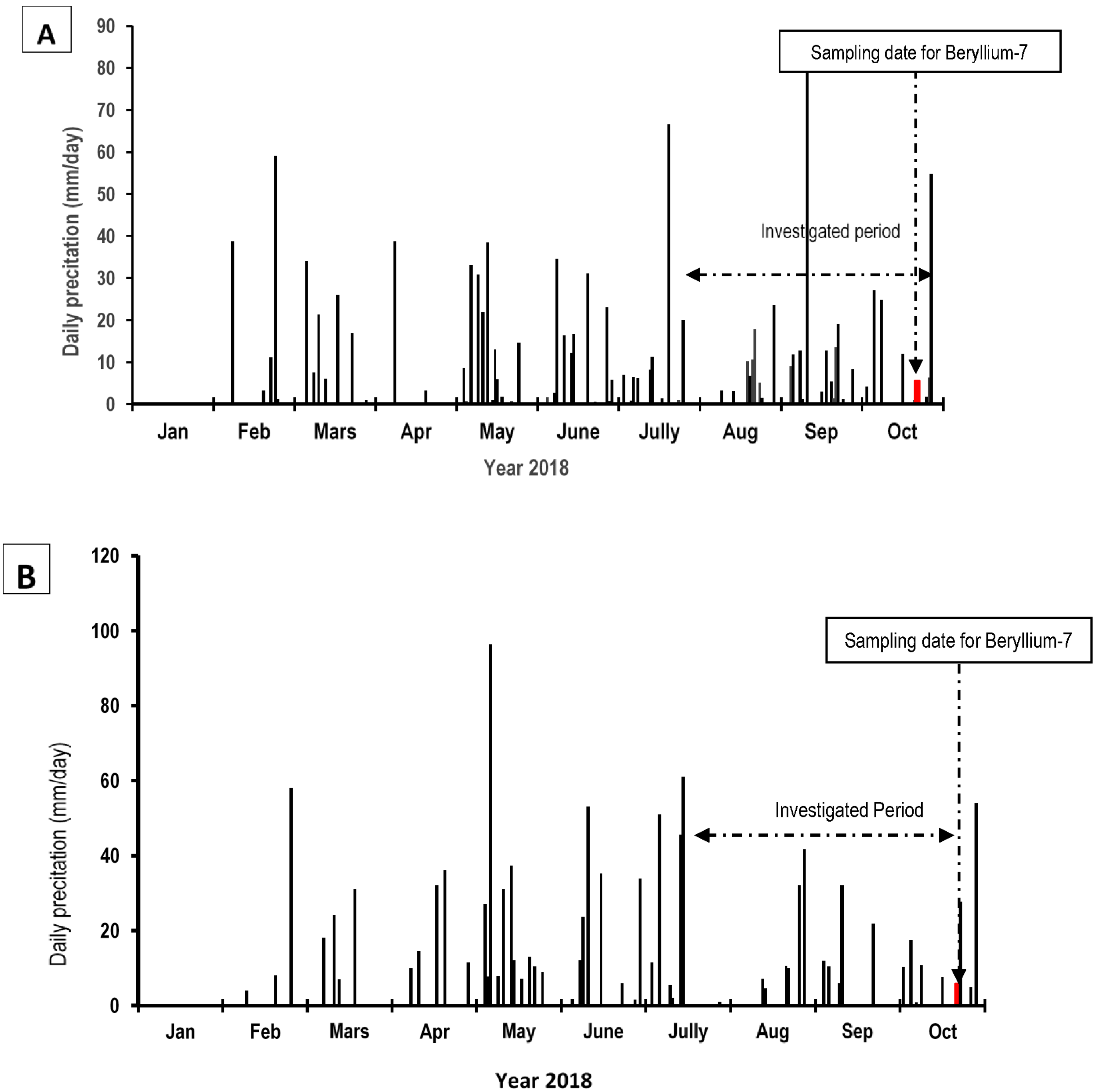


Figure 2:The daily precipitation recorded for the study sites (A = Dan and B = Za-Zounmè) for the period from January 1 to October 31, 2018. The arrow shows the date of the soil sampling for 7Be measurements (October 21, 2018 at Dan and October 22, 2018 at Za-Zounmè)

2.2. Experimental design

Maize (*Zea mays* L.) was selected as the suitable crop for this investigation of the tillage and mulch impact on soil erosion because it is commonly frown in this area and it has low soil conservation efficiency. The planting density was 35,000 seed hills/ha. The experimental design was Randomly Complete Block with tree replications. The treatments combined three tillage practices: NT (no-tillage); SR (slope ridging, i.e. ridges parallel to the slope); CR (contour ridging, i.e. ridges parallel to contours) and three amounts of mulch: 0M (0 t ha^{-1}); 3M (3 t ha^{-1}) and 7M (7 t ha^{-1}). Maize stover (C:N ratio = 46) was applied for the mulch treatments. In all seasons mulch levels of <3 t ha^{-1} were used because cereal stover yields of up to 3 t ha^{-1} are achievable on smallholder farms in central Benin (Saïdou et al. 2018, Akplo et al. 2020). Mulch levels of 7 t ha^{-1} were selected in order to assess if there is any yield benefit in increasing surface cover beyond 4 t ha^{-1} which normally gives the minimum 30% cover for Conservation Agriculture systems (Erenstein, 1997). Being the farmer's practice, slope ridge system was used as control in this experiment. The construction of ridges was done manually using hoe and tape measure. The ridges were oriented in slope direction in the slope ridge system) or along the contour lines in contour ridging system. The ridges were 60 cm wide and 20 cm high. On both SR and CR plots, the distances between the ridges were 0.80 cm. In the CR system, ridges were made following the width of the plots. So, eight ridges of 3.5 m in length were made of each plot of CR system. In the SR system, ridges were made along the length of the plot and five ridges of 6 m in length were made in SR system. In no-tillage system, the crop was sowed directly without any soil preparation. The seedling poop was done with a machete or hoe. The mulch was made using vegetal residues. Runoff plots were established to evaluate the runoff amount as described in Akplo et al. (2022). Each plot was fenced from its surroundings by metal sheets embedded in the ground (Figure 3). The collection of runoff and sediment used fractional approach. At the lower end of the plots all runoff water and eroded soil was drained to a storage system composed of two tanks. The first tank was connected to each plot by a PVC pipe with 40 mm in diameter. It was pierced in its upper part with 8 identical holes, one of which was further connected to the second tank by a PVC pipe of 20 mm diameter while remaining 7 holes were draining the remaining water and soil to surrounding open space.

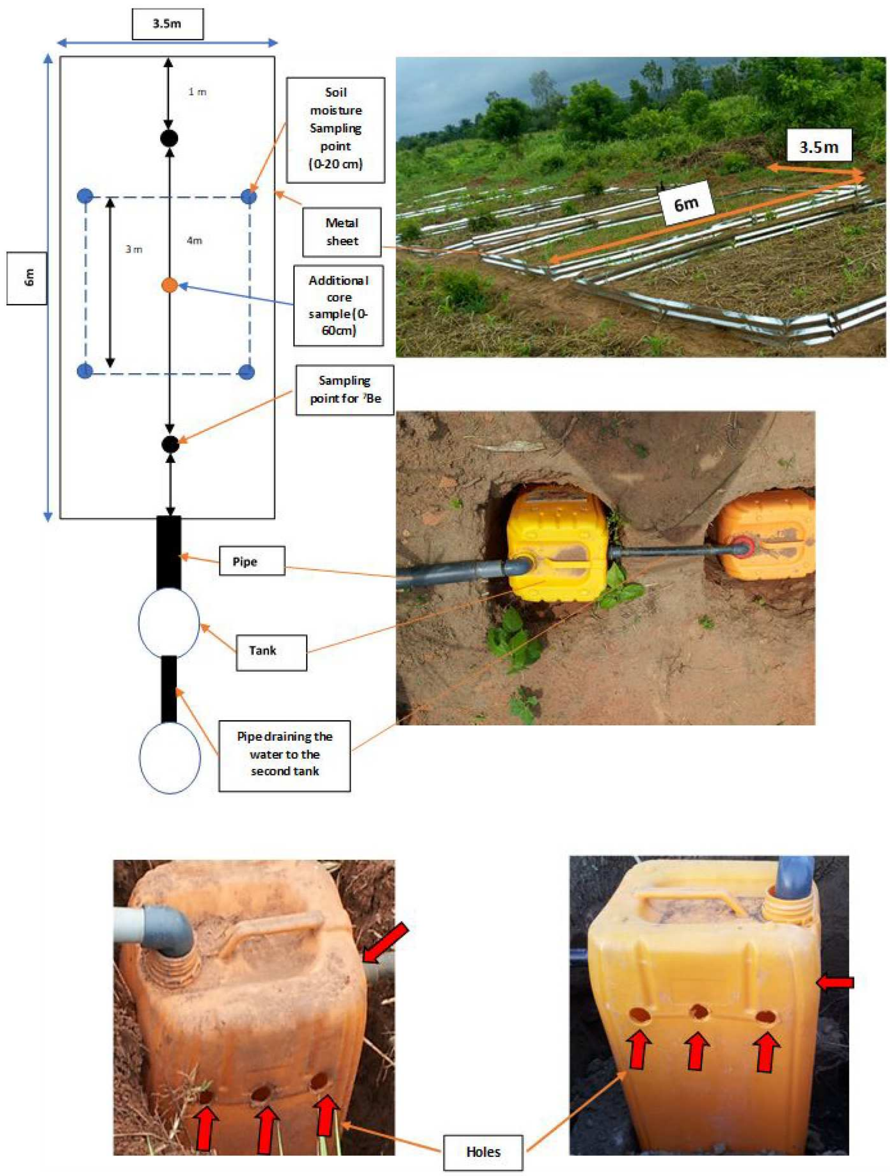


Figure 3 : The experimental field setup

2.3. Soil moisture assessment

Soil moisture (%) was determined for the 20 top centimeters after each rain of 40mm or more. In total 4 soil profiles forming a regular grid of 3m x 3m was installed (4 points) and the samples were taken at each side of the grid from the top to 20 cm in depth (Figure 3). In order to assess the effect of the tillage and mulching on the depth distribution of soil moisture, one additional core was sampled per plot from the top to 60 cm in depth at a resolution of 10cm (i.e.: 0-10 cm; 10-20 cm; 20-30 cm; 30-40 cm; 40-50 cm; 50-60 cm). Soil moisture was determined by ‘’thermo-gravimetric method’’ (Anderson & Ingram, 1993). The wet weight (P_W) of the samples was determined on site and the dry weight (P_D) determined in the laboratory after oven drying at 105°C until a constant dry weight. Soil moisture content (H) was determined by the following formula proposed by Saïdou et al. (2012):

$$\text{H}\ (\%) = (P_W - P_D)/P_D * 100$$

2.4. Runoff coefficient estimation

The total volume of each rain event was measured using rain gauge (iMETOS IMT280). Runoff was collected in the tanks with the installed receiving system. The runoff volume (V_r) was estimated as follows:

$$V_r = V_1 + (ß * V_2)$$

Where V_1 is the volume of runoff in the first tank; V_2 is the volume of runoff in the second tank; *ß* is a constant associated with the number of holes of the first tank (in our case, ß=8).

The runoff coefficient was estimated using the following equation:

$$R\ (\%) = (V_r/V) * 100$$ Where V= the total rain amount (in liter)

2.5. Principle of erosion estimation using ^{7}Be tracer

The ^{7}Be-method, similarly as other FRN methods is based on ^{7}Be occurrence only in uppermost soil layer (as it was deposited from atmosphere) an its immobility in soil. The origin of ^{7}Be is cosmogenic and it is created by interaction of cosmic rays with atmosphere. The estimation of soil erosion rates is based on comparison of ^{7}Be inventories (Bq m^{-2}) at studied site with reference inventories representing soil undisturbed by erosion (Mabit and Blake, 2019; Blake et al., 2002; Schuller et al., 2006; Walling et al., 1999; Sepulveda et al., 2008; de Rosas et al., 2018; Taylor et al., 2013). When the value of the inventory at the study site is lower than the value of the reference inventory there is erosion and in the opposite case, there is deposition. A simple conversion model (Profile Distribution Model, PDM) based upon the ^{7}Be depth distribution is used to convert the ^{7}Be inventory measurements into quantitative soil erosion or deposition rates (Blake et al., 1999; Taylor et al., 2019).

2.6. Sampling strategy for ^{7}Be determination

The present investigation was undertaken for the period of heavy rain events from September 2018 to October 2018. The fields were under fallow since 2000. The treatments had been installed since 10th May 2018 at Dan and 12th May 2018 at Za-zounmè. The soil sampling for Be-7 was done on October 21th, 2018 at Dan and October 22nd, 2018 at Za-zounmè. Since fallout radionuclides (i.e., ^{137}Cs; $^{210}Pb_{ex}$; ^{7}Be) were used as soil tracers, the redistribution rate assessment is based on comparing the inventory measured at a given sampling site with a reference site. Indeed, when the value of the inventory at the study site is lower than the value of the reference inventory the sampled site is affected by erosion and in the opposite case it is affected by deposition (Sepulveda et al., 2008; de Rosas et al., 2018). For 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 2016 and without evidence of soil redistribution (erosion or sedimentation). Ten cores were taken following a grid approach (Mabit et al., 2014) for the reference inventory estimation. 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.

Two soil cores (Ø = 25 cm, h = 3 cm) were sampled at each experimental plot (Figure 4), in its upper and lower part of the plot using a surface cylindrical collector. The sampling points were at 4m distance each from the other). 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 beryllium 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. Collected samples were air-dried, grinded by hand and sieved at 2 mm.

2.7. Gamma spectrometry analysis

^{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. ^{7}Be activity was determined from the net peak area of gamma ray at 477.6 keV (emission intensity of 10.4% Energy and efficiency calibrations were performed by 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 100ml. 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 approximately 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):

$$\frac{\lambda t}{1-\exp(1-\lambda t)}$$

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

2.8. Estimation of soil redistribution using ^{7}Be tracer

As explained above, stable reference site was selected to measure the baseline ^{7}Be inventory, which is compared with the ^{7}Be inventory at the sampling locations. We used the Profile distribution model (PDM) described in Blake et al. (1999) to convert the ^{7}Be inventories into erosion or deposition rate. This model is based on the depth distribution of the radionuclide in the soil column at undisturbed site. Soil mass depth is used to measure depth in soil and is 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 (Sepulveda et al., 2008; Zhang et al., 2014; de Rosas et al., 2018) and can be expressed as:

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

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 is found above and is used to quantify the ^{7}Be penetration into soil (Zhang et al., 2014; Ryken et al., 2018).

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

$$A\ (0) = A_{ref} = \int_0^{\infty} C(x)dx = C(0)h_0$$

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

$$A\ (x) = \int_{-x}^{\infty} C(x)dx = A_{ref}\, e^{(x/h_0)}$$

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

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

Deposition of sediment is 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), can be calculated as:

$$x' = (A - A_{ref})/C_d$$

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:

$$C_d = \int_S x C_e \, dS / \int_S x \, dS$$

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

$$C_e = (A_{ref} - A)/x$$

2.9. Statistical analysis

Series of statistical analysis were performed. First, multi-site mixed-effect analysis 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 PROC MIXED procedure was conducted on each site. Tillage system and mulch input rates were taken as a fixed effect while block was considered as 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 was tested by Shapiro-Wilk test (Shapiro & Wilk, 1965) and by Bartlett test (Bartlett, 1937), respectively. Relationships between soil erosion variables and soil physical properties were assessed using Pearson correlation test. All statistical analyses were conducted in SAS 9.4 (SAS Institute, 2015) with an alpha of 0.05. Due to interactions between tillage and mulch input rates, the main effects were not reported.

3. Results

3.1. Tillage and mulching effect on soil moisture

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 1). At both sites, the gravimetric soil moisture content was lowest on the NT0M plots (12.55% at Dan and 6.33% at Za-zounmè) and 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 also on the soil moisture in the deeper part of soil profile (below 30 cm). The depth distribution of soil moisture is shown on Figure 4. For all treatments the moisture in deeper part of 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 pronounced especially if the amount of mulch is great. The differences between 7 tons of mulch and 3 tons of mulch are usually greater than the differences between 3 tons of mulch and no mulch.

Table 1: Effect of studied treatments on soil moisture content of topsoil and runoff (mean ± standard deviation)

	Soil moisture content (%)		**Runoff coefficient (%)**	
Treatments	Dan	Za-zounmè	Dan	Za-zounmè
NT0M	12.55 ± 0.11e	6.32 ± 0.21c	1.26 ± 0.54b	2.19 ± 0.54b
NT3M	13.22 ± 0.55de	6.74 ± 0.31c	0.56 ± 0.18c	0.58 ± 0.22c
NT7M	15.68 ± 0.21bc	6.54 ± 0.1c	0.46 ± 0.11c	0.59 ± 0.1c
SR0M	14.98 ± 0.25c	6.25 ± 0.41c	4.56 ± 0.67a	3.89 ± 1.01a
SR3M	13.73 ± 0.06d	6.4 ± 0.49c	0.42 ± 0.13c	0.47 ± 0.19c
SR7M	16.29 ± 0.20b	8.55 ± 0.18b	0.22 ± 0.07d	0.2 ± 0.05c
CR0M	13.79 ± 0.42d	6.83 ± 0.19c	0.54 ± 0.1c	0.65 ± 0.06c
CR3M	17.48 ± 0.86a	6.99 ± 0.10c	0.40 ± 0.05c	0.44 ± 0.07c
CR7M	17.70 ± 0.60a	12.08 ± 0.19a	0 ± 0d	0 ± 0d
p-value	<0.0001	<0.0001	<0.0001	<0.0001

__NT0M__: No tillage + 0 t/ha of mulch; __NT3M__: No tillage + 3 t/ha of mulch; __NT7M__: No tillage + 7 t/ha of mulch; __SR0M: Slope__ Ridging + 0 t/ha; __SR3M: Slope__ Ridging + 3 t/ha of mulch; __SR7M: Slope__ Ridging + 7 t/ha of mulch; __CR0M:__ Contour ridging + 0 t/ha of mulch; __CR3M:__ Contour ridging + 3 t/ha of mulch; __CR7M__: Contour ridging + 7 t/ha of mulch.

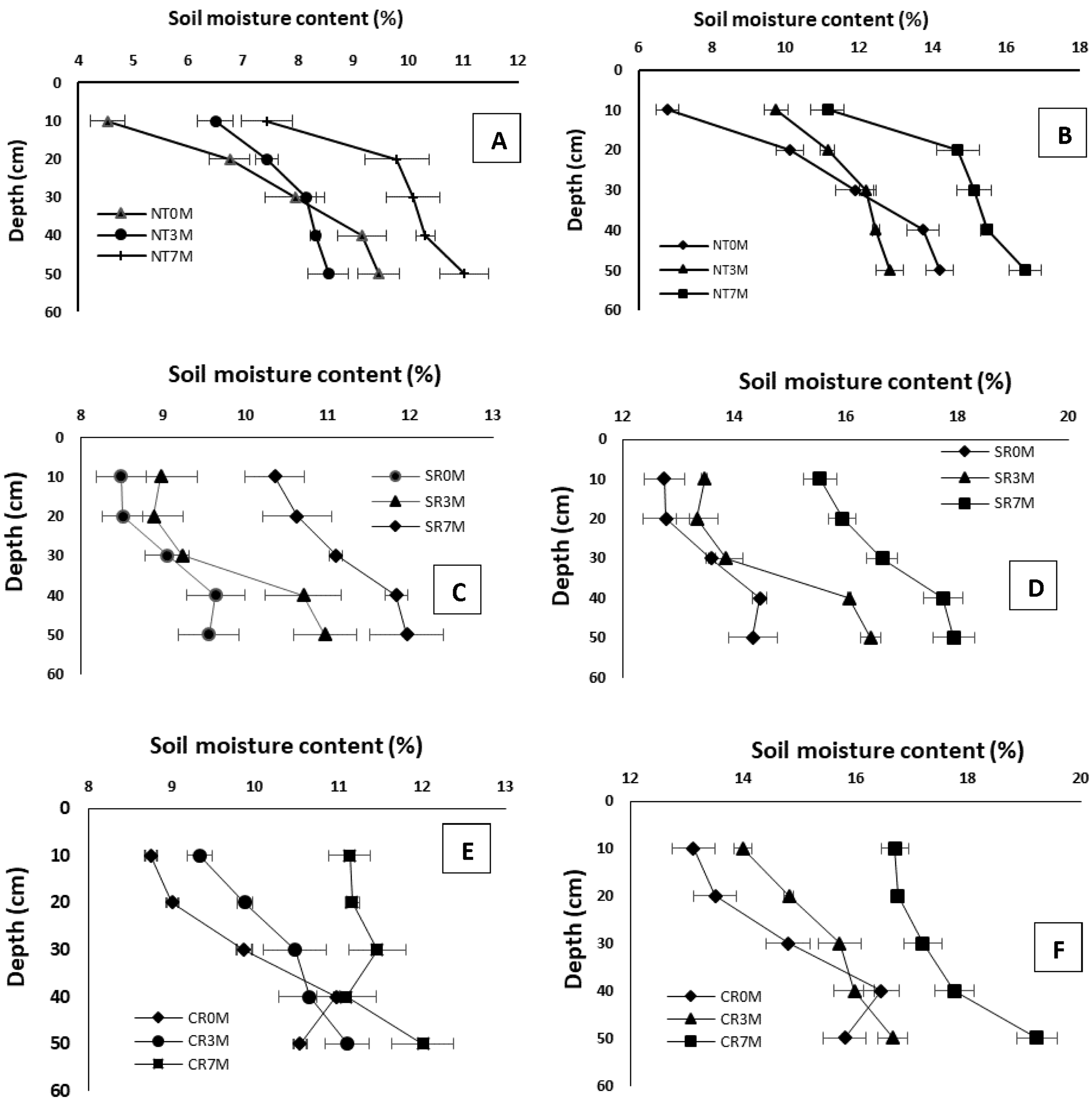


Figure 4: Effect of tillage and mulching on the depth distribution of soil moisture: a) no-tillage treatments at Dan; b) no-tillage treatments at Za-zounmè; c) slope ridging at Dan; slope ridging at Za-zounmè; e) contour ridging at Dan; f) contour ridging at Za-zounmè. The error bars represent the standard deviation for each treatment.

3.2. Tillage and mulching effect on runoff

At both Dan and Za-zounmè, the control (slope ridging + 0 t ha^{-1} of mulch, i.e. SR0M) recorded the highest runoff coefficient (4.56 ± 0.67% at Dan and 3.89 ± 1.01% at Za-zounmè) while the lowest runoff coefficient was obtained for contour ridging and 7 t ha^{-1} of mulch (Table 1). Compared with the control, NT0M, NT3M and NT7M respectively reduced the runoff coefficient by 70%; 88% and 90% at Dan and by 43%; 85% and 85% at Za-zounmè. However, the difference observed between the runoff coefficient recorded for the treatments NT3M and NT7M were not significant. The runoff coefficient of CR3M and CR0M were considerably lower as compared with the control. These treatments have reduced the runoff coefficient respectively by 91% and 88% at Dan and by 88% and 83% at Za-zounmè.

3.2.1. Sediment transport based on ^{7}Be measurement

The depth distribution of ^{7}Be at the reference sites is shown at 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} (respectively h_0= 5.75 at Dan and h_0= 5.46 at Za-zounmè), i.e., the upper 3 mm. We found initial ^{7}Be concentration C(0) of 55.58 Bq kg^{-1} and 78.51 Bq kg^{-1} at Za-zounmè and Dan respectively corresponding to an areal activity of 302 Bq m^{-2} and 451 Bq m^{-2} (Table 2). 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 3). 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 were considered (Table 3) and it was found that this fraction ranges from 4% (for 3 t ha^{-1} of mulch) to 16% (for 7 t ha^{-1} of mulch). By subtracting the

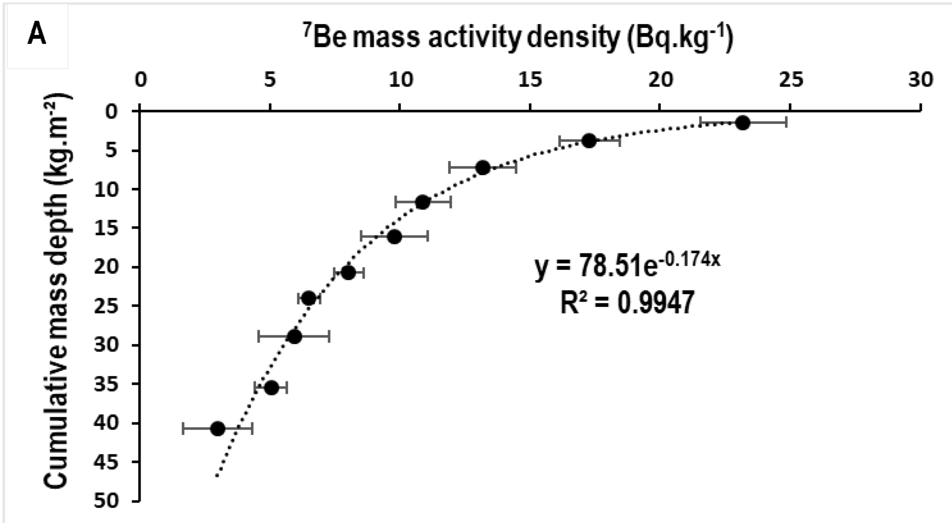
^{7}Be uptake by the mulch, the initial amount of ^{7}Be received by the soil (A_{used}) under each treatment were calculated (Table 3). At Dan, the inventory values used as reference are 392.78 Bq m^{-2} for the 0M plots; 377.12 Bq m^{-2} for the 3M plots and 352.91 Bq m^{-2} for the 7M plots and at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

Table 2. Expression of the initial 7Be 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

Table 3. ^{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



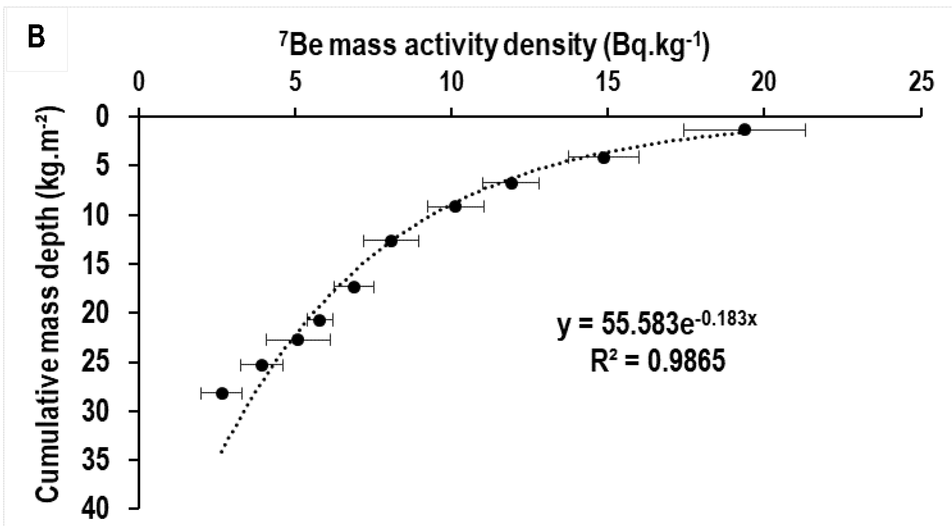


Figure 5: The depth distribution of 7Be mass activity: A) at Dan and B) at Za-zounmè. The error bars represent the precision of gamma spectrometry measurements at the 95% confidence level.

The ^{7}Be inventories (Bq m^{-2}) associated with the treatments are shown in Figures 6 and 7. 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 Bq m^{-2} to 390.62 Bq 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 upper and lower part 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 6) and

SR7M; CR3M and CR7M at Za-zounmè (Figure 7). 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 was higher than the reference inventory.

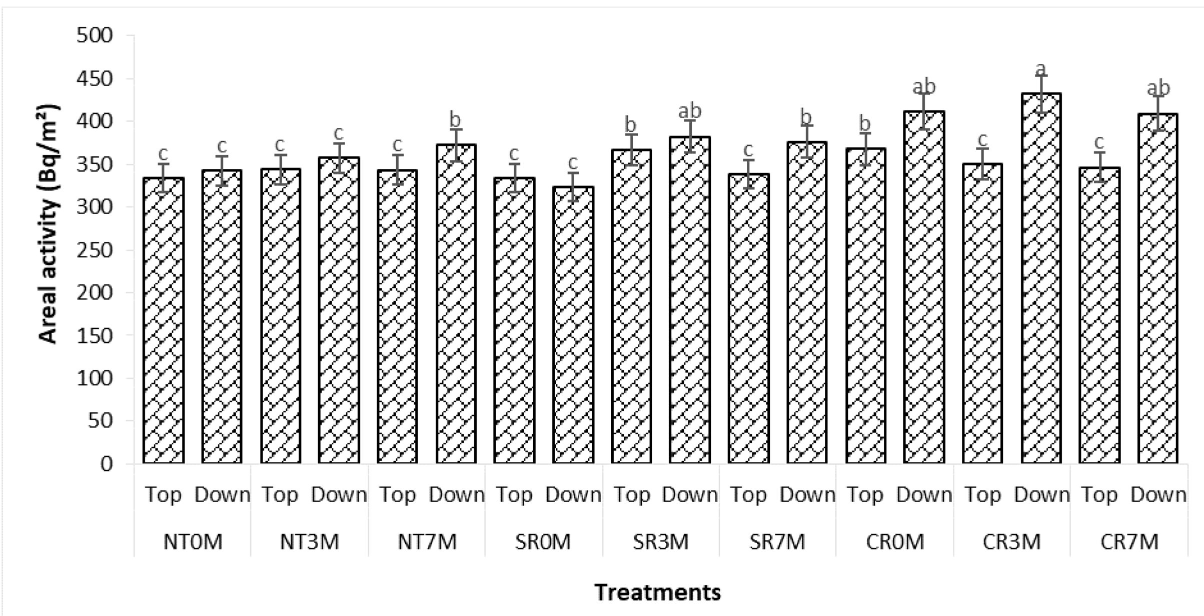


Figure 6 :Inventories of ^{7}Be in soil at Dan. *Means with the same lowercase letter are not significantly different among treatments. NT0M: No tillage + 0 t/ha of mulch; NT3M: No tillage + 3 t/ha of mulch; NT7M: No tillage + 7 t/ha of mulch; SR0M: Slope Ridging + 0 t/ha; SR3M : Slope Ridging + 3 t/ha of mulch; SR7M : Slope Ridging + 7 t/ha of mulch; CR0M : Contour ridging + 0 t/ha of mulch; CR3M : Contour ridging + 3 t/ha of mulch; CR7M: Contour ridging + 7 t/ha of mulch.*

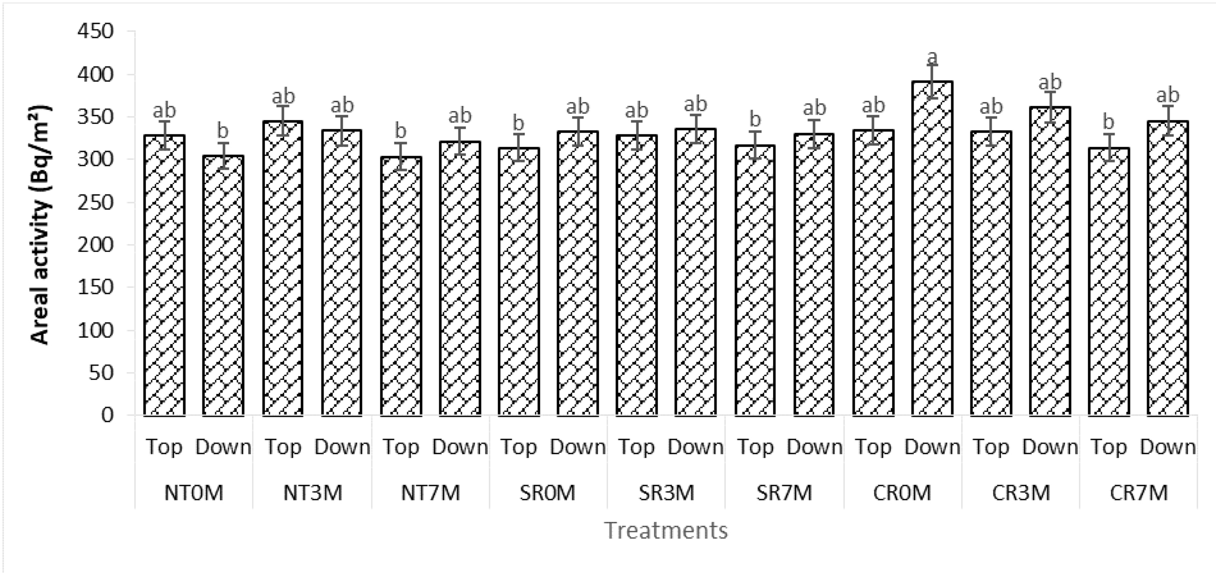


Figure 7: Inventories of 7Be in soil at Za zounmè. *Means with the same lowercase letter are not significantly different among treatments. NT0M: No tillage + 0 t/ha of mulch; NT3M: No tillage + 3 t/ha of mulch; NT7M: No tillage + 7 t/ha of mulch; SR0M: Slope Ridging + 0 t/ha; SR3M: Slope Ridging + 3 t/ha of mulch; SR7M : Slope Ridging + 7 t/ha of mulch; CR0M : Contour ridging + 0 t/ha of mulch; CR3M : Contour ridging + 3 t/ha of mulch; CR7M: Contour ridging + 7 t/ha of mulch.*

The total soil loss estimated with the ^{7}Be methodology had a similar trend as the soil losses measured directly, with high soil losses with the control treatment and a decrease in soil loss with the no-tillage and contour ridges treatments (Table 4). However, the ^{7}Be methodology resulted in an overestimation of the total soil loss for most plots. At Dan, the highest soil erosion was obtained for SR0M (10.19 t ha^{-1}) and highest soil deposition for CR7M (4.06 t ha^{-1}). The treatments NT0M; NT3M; SR0M; SR3M and CR0M showed erosion while the treatments NT7M; SR7M; IR3M and CR7M show deposition. At Za-zounmè, the treatments NT0M; NT3M; NT7M; SR0M; SR3M; CR0M and CR3M show erosion whereas deposition was obtained on SR7M and CR7M. The highest soil erosion was obtained with NT0M (-7.36 t ha^{-1}) and the highest soil deposition was observed with CR7M (3.93 t ha^{-1}). The obtained data showed that both mulch and tillage have significant impact on soil erosion. Mulch is efficient especially if great amounts (7 t ha^{-1}) are used and among three tested tillage approaches the contour ridging is most efficient. The mean soil redistribution rates for all plots under these two treatments reached

0.9 t/ha for plots with 7 t $ha^{-1}$of mulch and 0.4 t ha^{-1} for plots with contour ridges. This is very good result as both these conservation measures entirely prevented net soil erosion and only limited soil redistribution took place at these experimental plots resulting in minor net deposition. The relationship between the soil loss and some characteristics of the sol is shown in table 5. It was found out that soil loss is significantly ($p < 0.05$) correlated with the amount of the mulch (r= -0.73), soil water content (r=-0.91), runoff (r=0.63) and soil organic matter content (r=-0.75) at Dan. At Za-zounmè, significant correlation was observed between soil loss and the amount of the mulch (r= -0.82), soil water content (r=-0.86), runoff (r=0.67) and Field Water Holding capacity (r=-0.63).

Table 4. Soil redistribution for the studied treatments estimated by ^{7}Be-method

Treatments	**Total soil loss (t ha^{-1})**	
	Dan	Za-zounmè
NT0M	-8.63 ± 1.06	-7.36 ± 2.85
NT3M	-4.19 ± 1.49	-2.80 ± 1.27
NT7M	0.80 ± 3.31	-1.69 ± 2.22
SR0M	-10.19 ± 1.30	-6.13 ± 2.30
SR3M	-0.38 ± 1.65	-4.03 ± 0.90
SR7M	0.69 ± 3.35	0.23 ± 1.69
CR0M	-0.52 ± 4.60	-2.89 ± 1.91
CR3M	2.07 ± 8.93	-1.57 ± 3.22
CR7M	4.05 ± 7.28	3.93 ± 2.34

***NT0M**: No tillage + 0 t/ha of mulch; **NT3M**: No tillage + 3 t/ha of mulch; **NT7M:** No tillage + 7 t/ha of mulch; **SR0M: Slope** Ridging + 0 t/ha; **SR3M : Slope** Ridging + 3 t/ha of mulch; **SR7M** : **Slope** Ridging + 7 t/ha of mulch; **CR0M** : Contour ridging + 0 t/ha of mulch; **CR3M** : Contour ridging + 3 t/ha of mulch; **CR7M**: Contour ridging + 7 t/ha of mulch.*

Table 5: Pearson correlation coefficients between soil loss rate and soil properties

Parameters	**Soil loss (t/ha)**	
	Dan	Za-zounmè
Mulch amount (t/ha)	-0.73*	-0.82**
Soil Moisture (%)	-0.91***	-0.86**
Runoff coefficient (%)	0.63*	0.67*
Organic matter content of the soil (g/kg)	-0.75*	-0.13ns
pF 2.5 (mm)	-0.82ns	-0.63*
pF 4.2 (mm)	-0.41ns	0.03ns

4. Discussion

The results of this study showed a significant integrative effect of tillage and mulching on the soil water content and runoff. The impact of tillage and mulching on the water storage is recognized worldwide (Roger-Estrade et al., 2010). In this study, it was found that for the same mulch amount, the highest water content and conversely the lowest runoff coefficient were associated with the contour ridges. For the same tillage treatment, the water content significantly had increased, whereas the runoff coefficient had significantly decreased with the mulch amount. Then, the integrative treatment combining contour ridging and 7 t ha^{-1} of mulch had yielded the higher water content of soil (17.7% at Dan and 12.1% at Za-zounmè) and had totally prevented the runoff at both investigated sites. These results showed that the ridges oriented along the contour direction act as efficient obstacle for runoff and consequently they contribute to infiltrating and retaining water at the slope. The major effect of mulch cover is reducing soil evaporation. Douzet et al. (2010); Mazarei & Ahangar (2013) and Houngnandan et al. (2018) reported a 10-50% reduction in soil water evaporation as a result of soil mulching. The quantities of mulch have greater impact on soil moisture especially in the topsoil, but they are detectable also in deeper layers, although here the differences are smaller. Interesting feature is that at both sites, the difference in the soil moisture between topsoil and deeper layers is greatest for NT0M treatment and this treatment although in topsoil it has soil moisture lower than NT3M treatment (as it is for all tillage treatments) in the deeper layers it has soil moisture considerably higher than NT3M treatment. This can be explained by occurrence of great amount of continuous vertical macropores which are known to develop usually under no tillage treatment. These macropores significantly increase soil permeability and help to drain rainfall to deeper part of the soil profile. If mulch is present on the soil surface it results in ponding and interception and thus hinders quick infiltration. This could probably cause the greater contrast between soil moisture of topsoil and subsoil under NT treatment without mulch and NT treatment with mulch than what is between soils under CT and ST.

The tillage and mulching have significant effect also on soil erosion. The lowest soil erosion was recorded under contour ridging (CR) at both sites. These findings are in line with the results reported in the literature according to which the adequate tillage systems are key soil water conservation measures (Kurothe et al., 2014; Akplo et al., 2017). Contour ridges stop the runoff completely or at least reduce its velocity, giving thus water more time to infiltrate, and deposit detached soil particles. It retains sediments in the field. In contour farming, ridges and furrows are formed by tillage. Unfortunately, slope ridge (SR) practice is the most common tillage approach used by the local farmers in Benin. The impact of mulch on soil erosion is based on two particular effects. First, the crop residues covering the soil surface protect soil aggregates from mechanical impact of falling rain drops and this prevents the detachment of soil particles and reduces the amount of soil material mobilized by runoff. Secondly, the crop residues are an obstacle for runoff, they reduce its speed and thus reduce its transporting capacity.

The high erosion rate observed under NT management as compared to the CR management is in contrary with the results of Ouattara et al. (2018) and Ryken et al. (2018) who reported that under no-tillage system the soil erosion is lower than under conventional tillage. However, Akplo et al. (2017) showed that at short slopes the soil loss amount was 20-30 times lower for contour ridging as compared to no-tillage in the watershed of Linsinlin in central Benin. In general, the conservational effect of NT practices are associated with a transition phase of 7-8 years (on average) characterized by high soil erosion (Pagnani et *al*., 2019). Soil needs time to develop continuous macropores improving its permeability. This can explain the high soil erosion obtained under no-tillage in this study since as NT was introduced just two years ago.

The results showed that NT is effective in soil erosion controlling if associated with 7 t.ha^{-1} of mulch. The positive effect of mulch on soil and water conservation is widely documented (Uwizeyimana et al., 2018; Roger-Estrade et al., 2010; Kurothe et al., 2014). Soil water content consistently increased with increase in surface cover across the three tillage practices. Treatments that received 7 t ha^{-1} of mulch cover had the highest soil water content. The findings of the present study show that the lower runoff rates were obtained under the treatments that received 7 t ha^{-1} of mulch at both studied sites. This means that 7 t ha^{-1} of mulch cover is effective in water conservation and soil erosion control under the agroclimatic conditions typical for Benin. The role of crop residue cover in soil erosion control is based on reducing the erosive power of falling rain drops and reducing the volume and velocity of runoff (Guto et al. 2012). However, to have real benefit from mulch, a great quantity should be applied. 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. While the direct measurements were incapable to identify deposition points, the Be measurements indicate deposition under certain treatments (e.g. CR7M). However, estimates of soil redistribution based on the 7Be measurements were an overestimation relative to the direct soil loss measured. This can partially be related to the point sampling of the ^{7}Be methodology. Possible deposition or eroding areas within the experimental plot can be unsampled (Ryken et al., 2018). In addition, as demonstrated in Taylor et al. (2014), Be is preferentially adsorbed to the fine particle fraction of the soil and then eroded with fine particle more quickly than the coarser fraction. This may result in an overestimation of erosion by ^{7}Be method (Yang et al., 2013).

The SR tillage is a dominant land management in Benin. But because it has its negative impacts such as soil erosion and nutrients as soil water loss, the NT should be recommended as an effective land management controlling soil erosion and improving soil quality. However, the feasibility of NT for smallholder farmers in Benin is 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 agroecosystems and adaptation to the agroecological conditions and the managerial, agrotechnical, and economic conditions of the farming (Erenstein et al., 2012). For example, the first condition would be a broad availability of appropriate machinery for no tillage sowing. Hand no tillage sowing equipment is produced for example in Brazil and was successfully tested at experimental fields in Zimbabwe under the IAEA funded technical cooperation project RAF5075 'Enhancing Regional Capacities for Assessing Soil Erosion and the Efficiency of Agricultural Soil Conservation Strategies through Fallout Radionuclides' (Figure 8).

Figure 8: Hand sowing equipment tested at experimental fields of Chemistry and Soil Research Institute, Ministry of Agriculture, Mechanization and Irrigation Development, Zimbabwe

5. Conclusion

Soil and water conservation are among keys challenges to achieve food security in sub-Saharan Africa. The present study explored the efficiency of two practices of soil and water conservation at plot-scale at two selected experimental sites in central Benin. The findings revealed that tillage and mulching significantly influence runoff, soil water content and erosion. At Dan, no-tillage with 7 $t.ha^{-1}$ of mulch (NT7M); contour ridging with 3 $t.ha^{-1}$ of mulch (CR3M) and contour ridging with 7 $t.ha^{-1}$ of mulch (CR7M) are associated with high soil water content and low runoff and soil erosion. At Za-zounmè, contour ridging with 7 $t.ha^{-1}$ of mulch (CR7M) is associated with high water content of soil and low runoff and soil erosion. Then no-tillage with 7 $t.ha^{-1}$ of mulch (NT7M), contour ridging with 3 $t.ha^{-1}$ of mulch (CR3M) and contour ridging with 7 $t.ha^{-1}$ of mulch (CR7M) can be adopted for water erosion controlling and water conservation. However, contour farming is most efficient on slopes between 2 and 10 %. In the long-term, it should be better if farmers would adopt no-tillage practice because of its long-term sustainable positive impact on the soil quality. Farmers should retain in-situ stalk of corn. Residues of soybean or other residues of the previous crop should be left on the field and the seeding of the next crop should be done without turning the soil by tillage. Land managers and governmental agricultural decision makers should provide to farmers, the technical assistance and training them in using the soil conservation agricultural practices. Because the rainfall and erosion temporal dynamics and spatial distribution are very variable and the effect of the conservational practices is site-specific, future research should the done specially to assess the long-term effect of contour ridging and no-tillage on soil erosion in Benin.

Conflicts of interest:

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

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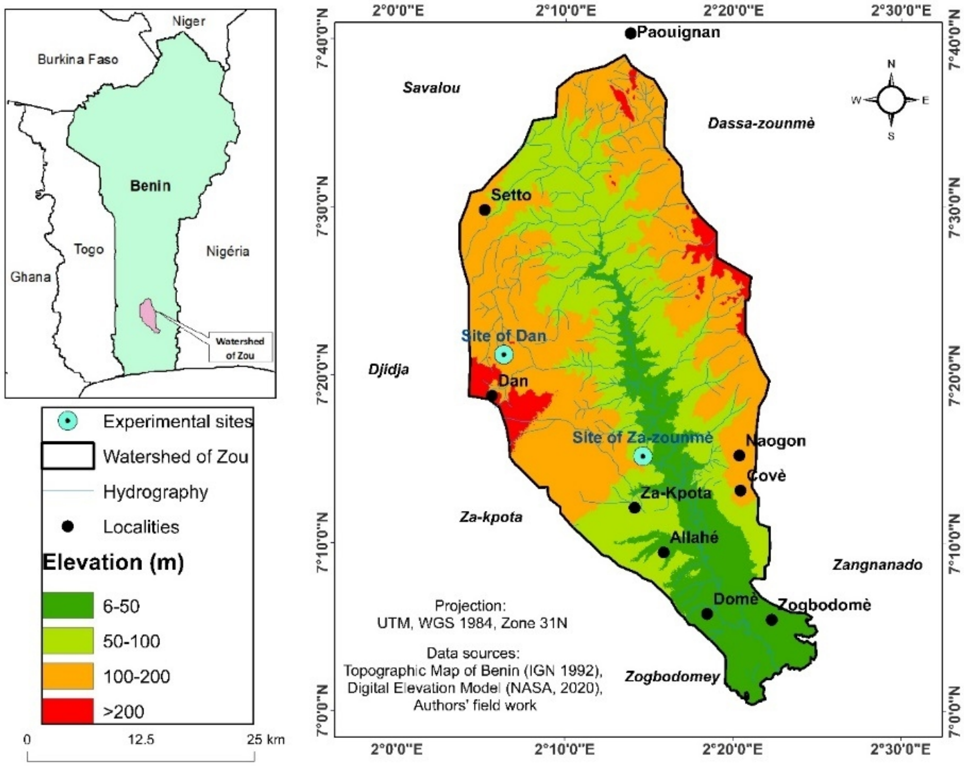
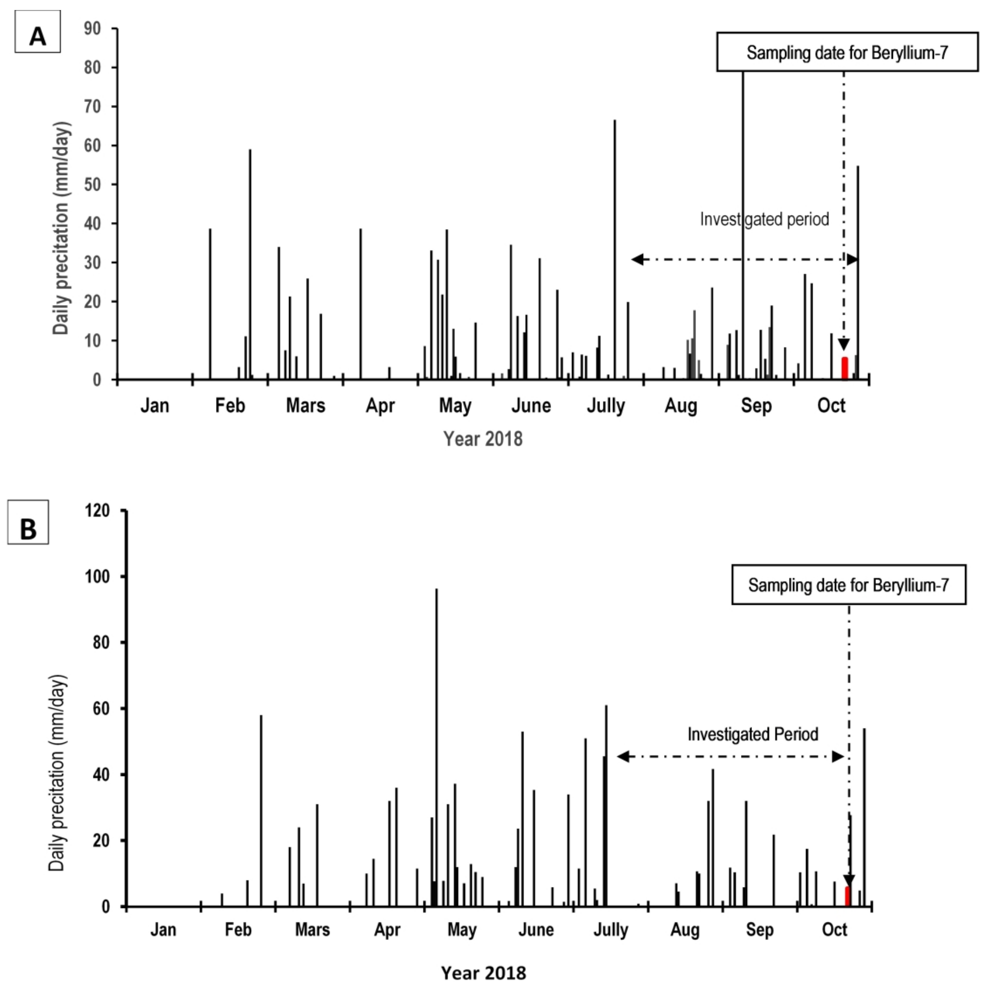


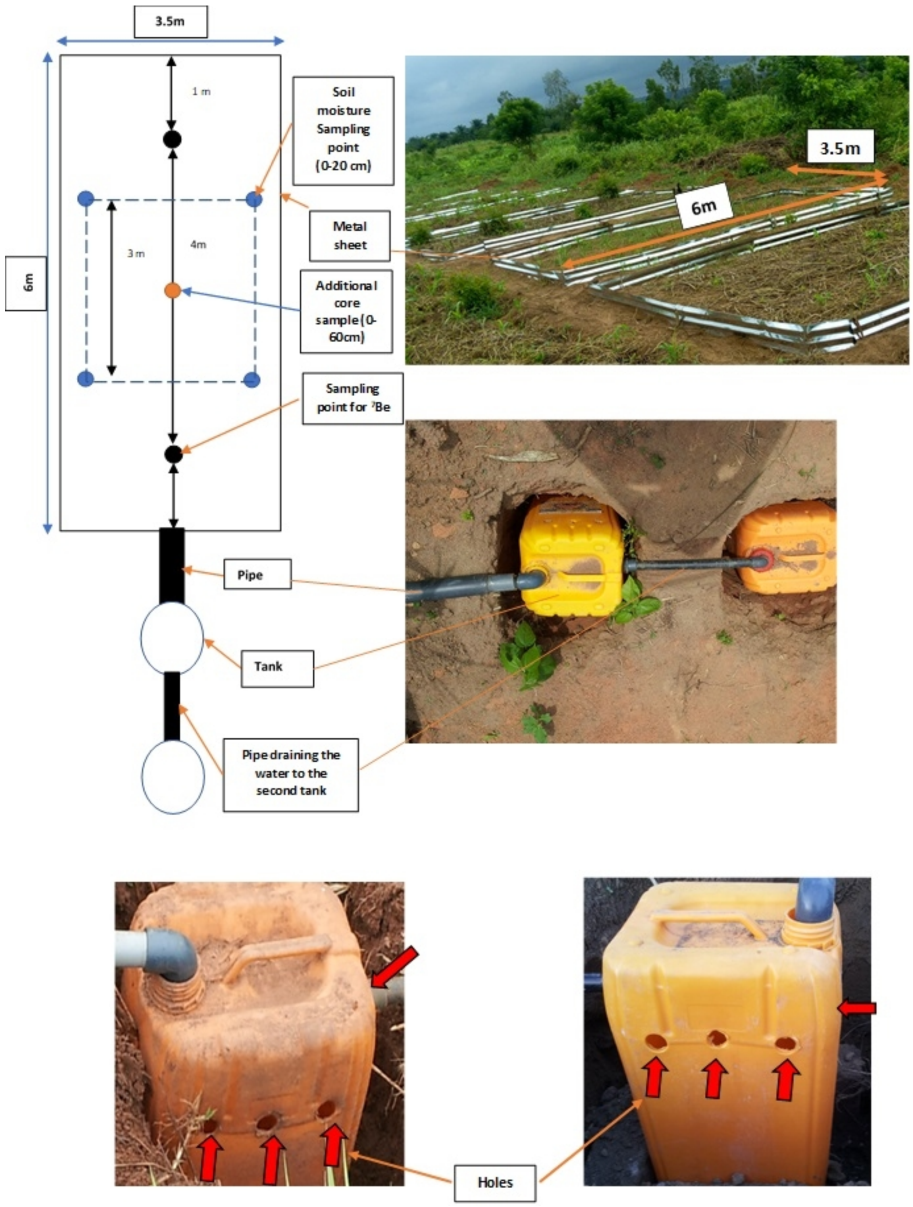
Watershed of Zou and experimental field location

108x83mm (220 x 220 DPI)



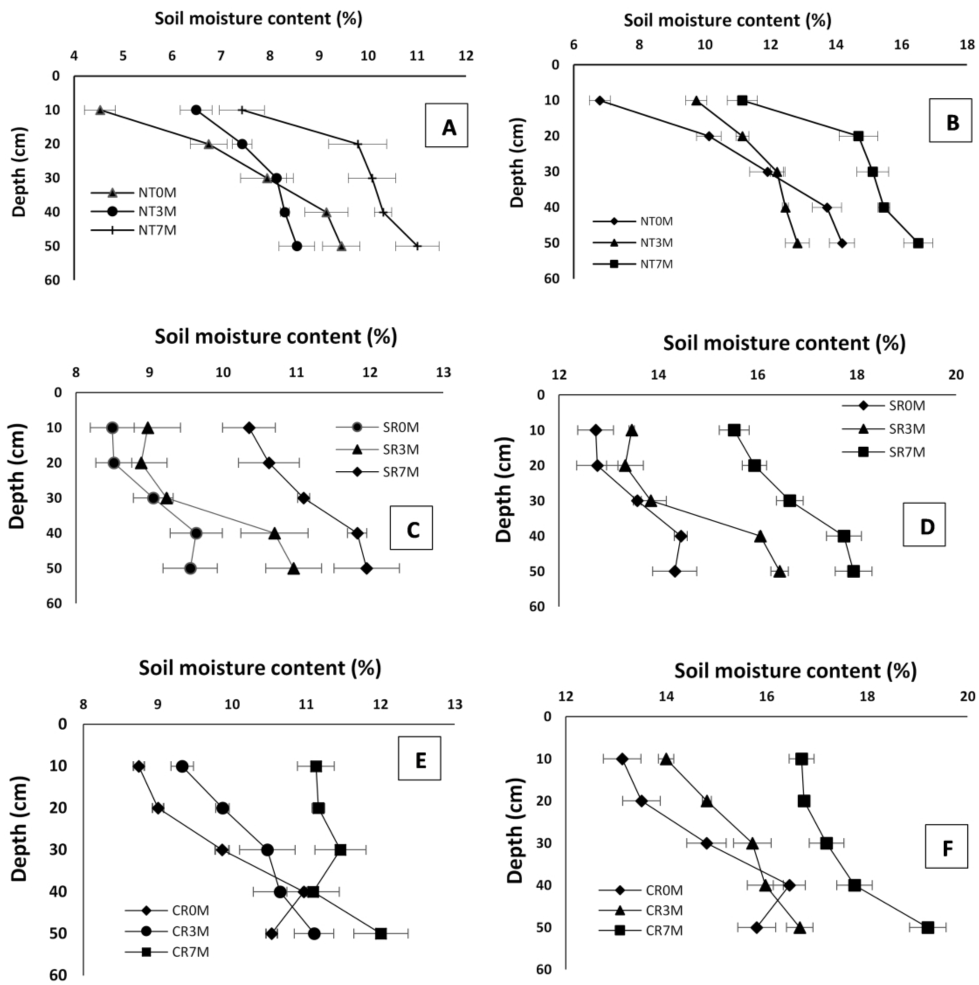
The daily precipitation recorded for the study sites

674x694mm (144 x 144 DPI)



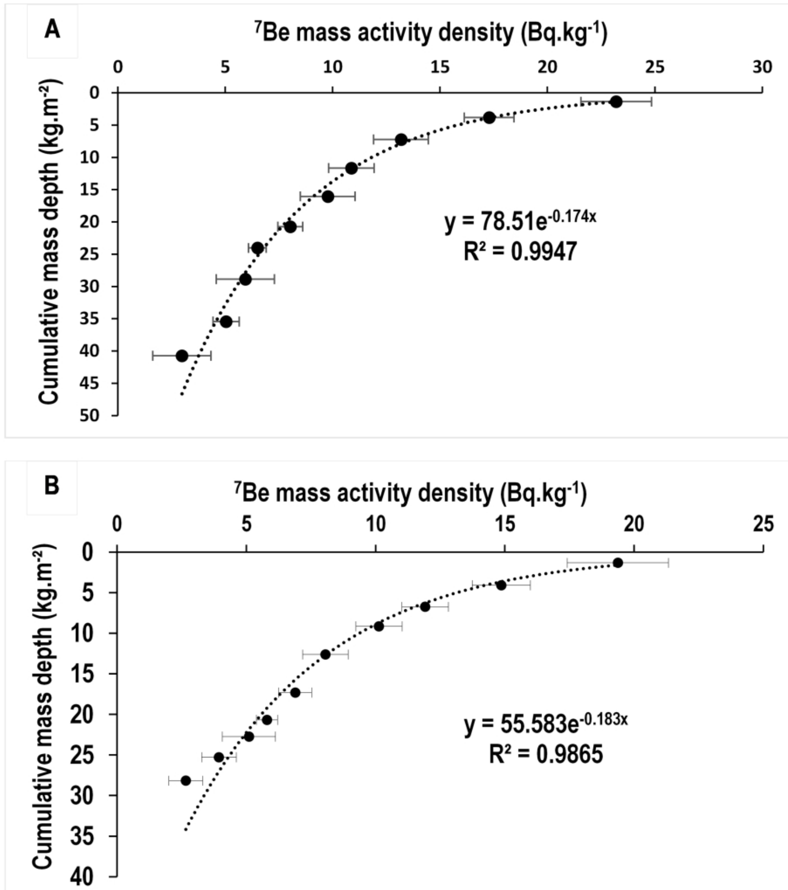
The experimental field setup

120x154mm (150 x 150 DPI)



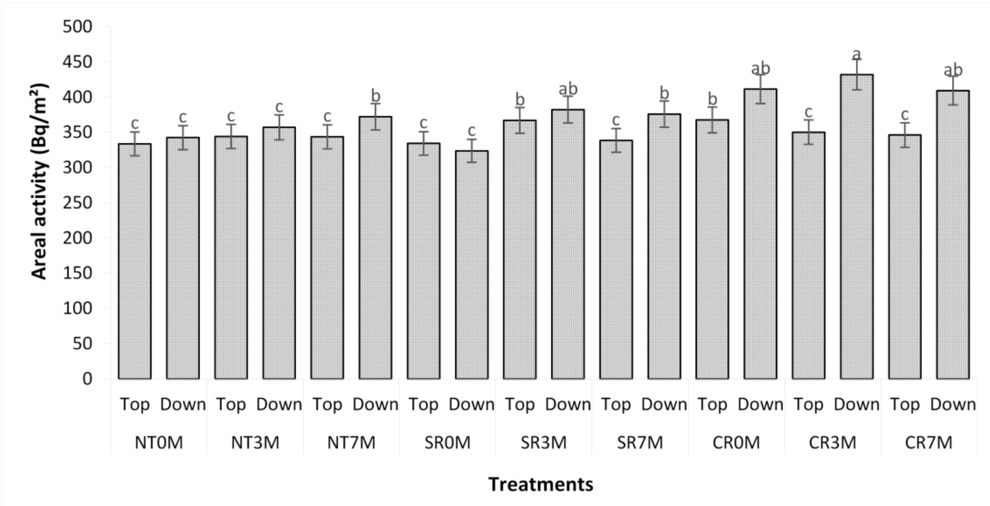
Effect of tillage and mulching on the depth distribution of soil moisture: a) no-tillage treatments at Dan; b) no-tillage treatments at Za-zounmè; c) slope ridging at Dan; slope ridging at Za-zounmè; e) contour ridging at Dan; f) contour ridging at Za-zounmè.

666x674mm (144 x 144 DPI)



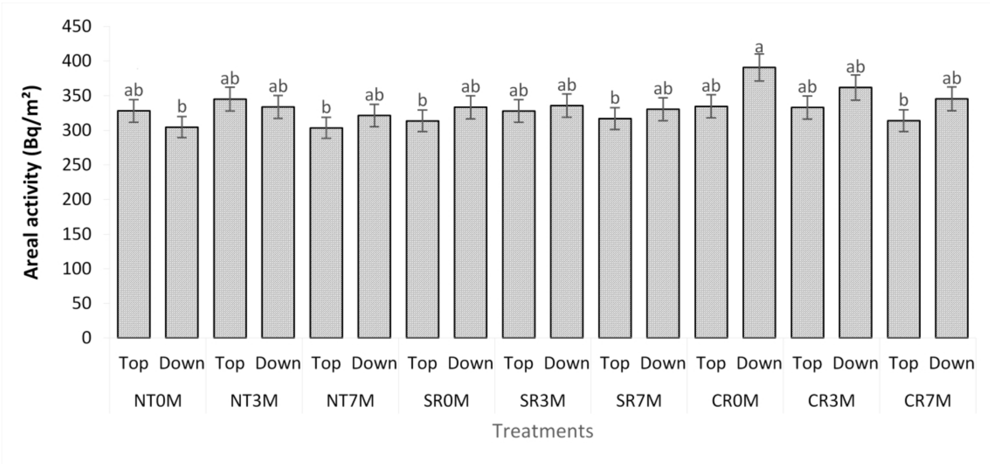
The depth distribution of 7Be mass activity: A) at Dan and B) at Za-zounmè

666x612mm (144 x 144 DPI)



Inventories of 7Be in soil at Dan

670x359mm (144 x 144 DPI)



Inventories of 7Be in soil at Za zounmè

676x332mm (144 x 144 DPI)

Hand sowing equipment tested at experimental fields of Chemistry and Soil Research Institute, Ministry of Agriculture, Mechanization and Irrigation Development, Zimbabwe

304x228mm (87 x 87 DPI)