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Evaluating the Effectiveness of Some Agricultural Practices Using ^{7}Be Fallout at Sehoul Catchment, Morocco

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ABSTRACT

Reliable information on soil loss is essential to establish the effectiveness of soil management practices. The present work aims at assessing short-term soil erosion and evaluating the efficiency of some agricultural practices, through the use of Beryllium-7 fallout technique. Sehoul catchment is located 40 km far from Rabat, between Maamora forest in the north and Grou River in the south. This region is subjected to significant soil degradation due to intense rainfall. The area suffers from mismanaged practices which deteriorate existent agricultural lands. The existent agricultural practices are Monoculture (MC), Cereal/Cereal Rotation (CCR) and Legume/ Cereal Rotation (LCR). Three representative fields including Vineyard as MC, Barley/Wheat as CCR and Bean/Wheat as (LCR), were investigated in 2009 and 2010. In 2009, results showed that the estimated net erosion rates were -6.7, -5.8, and 0.9 t ha^{-1} for CCR, LCR and MC, respectively, at a rainfall amount of 664 mm showing that MC is the best conservation practice followed by LCR then CCR. In 2010, the rainfall amount increased to 929 mm and the estimated net erosion rates were -13.9, 1.7, and -3.3 t ha^{-1} for CCR, LCR, and MC respectively, showing a decrease in soil loss in LCR despite heavy rainfall and emphasis that LCR is the best-recommended conservation practice followed by MC then CCR. Comparing the average net erosion rate for different agricultural practices for the two years, we can conclude that LCR is the most efficient conservation practice, particularly under heavy rainfall.

KEYWORDS

Soil erosion, 7Be activities, Gamma spectroscopy, agricultural practices.

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INTRODUCTION

Land degradation are among the main challenges facing agricultural sector in arid, semi-arid and even subhumid areas which increase soil desertification and decrease soil productivity. Water erosion is one of the major problems that threaten economic and agricultural social development. Soil erosion causes reduction in soil fertility, which leads to the progressive disappearance of arable lands, and contributes significantly to sedimentation in water reservoirs. The increasing of extreme weather events as a result of climate change will deteriorate soil fertility (**Dagan *et al*., 2012; Qadir *et al*., 2011**). Soil erosion is not always due to hostile climate, but can result from land mis-management and inappropriate policies (**Boardman et *al.,* 2003; Fullen 2003**).

Globally, more than 75% of the surface land area are affected by erosion is located in developing countries of Africa, Asia and Latin America, with about 50% in Asia (**Walling *et al.,* 1995**), and about 12% of the land area in the European Union is threaten by water erosion (**Gallart *et al.*, 1994)**. The annual cost of soil loss is estimated to be US $400 billion per year (**Meliho *et al.,* 2019**).

In Morocco, water erosion is one of the major problems that hinder economic and agricultural social development (**Meliho *et al.,* 2019**). Approximately, 12.5 million hectares of farmland and rangelands are threatened by erosion and almost 40% of land in Morocco are affected by erosion (**FAO, 1977 and 1990)**. The overall estimated soil erosion rate in Northwestern Morocco increased from 31.68 t ha^{-1} y^{-1} to 34.74 to t ha^{-1} y^{-1} using the Universal Soil Loss Equation (USLE) and Geographical Information System (GIS). They suggested that soil erosion is straightly influenced by the land use types existing in the watersheds (**Ben Hamman *et al.*, 2015)**.

One of the most powerful techniques to assess short term water erosion is the ^{7}Be technique. Beryllium-7 (^{7}Be) has half-life of 53.3 days, occurs in the upper troposphere and lower stratosphere and is produced naturally by spallation reactions of cosmic rays and solar energetic particles with atoms of nitrogen and oxygen (**Schuller *et al.,* 2006**). The Beryllium-7 decays to Lithium-7 through electronic capture which produced a gamma decay emission at energy of 477.8 keV, which it is easily measured by gamma ray spectrometry.

The Beryllium-7 is attached to airborne particles and its deposition to the earth's surface occurs continuously by wet and dry fallout (**Olsen *et al.,* 1985**). (**Wallbrink and Murray, 1994)** demonstrated that ^{7}Be fallout deposition is mainly associated with precipitation and will be rapidly and strongly fixed by the surface soil (**Hawley *et al,* 1986; Wallbrink and Murray, 1996; Kaste *et al.,* 2002**).

The principle of using the ^{7}Be technique is simple and based on comparing the inventories of the areas subjected to erosion or deposition with a reference plot, where neither erosion nor deposition have occurred (**Walling *et al.,* 1999**). Depletion of the ^{7}Be inventory relative to the reference inventory provides evidence of erosion, whereas areas of deposition are characterized by increased inventories. The extent to which the ^{7}Be inventory is decreased or increased should, in turn, provide a basis for estimating the magnitude of the erosion and deposition rates involved.

Beryllium-7 (^{7}Be) technique was successfully applied for estimating soil redistribution processes associated with individual events of heavy rain at scales ranging from plot size up to field scale. It can provide a reliable information on the rates of soil loss and lead to quantify the magnitude of soil erosion severity which is an effective parameter in the selection of effective strategies for soil conservation (**Kassab *et al.,* 2022 a,b; Mabit and Blake, 2019; Benmansour *et al.*, 2019; Benmansour *et al.*, 2011; Mabit *et al.,* 2008; Yoshimori, 2005; Taylor *et al.,* 2014; Duchemin *et al*., 2008; Daish *et al.,* 2005;**

Nouira *et al.*, 2003; Wilson *et al.*, 2003; Matisoff *et al.*, 2002; Blake *et al.*, 1999; Walling *et al.*, 1999).

The present work aimed at assessing the erosion rate and evaluating the effectiveness of some agricultural practices in Sehoul region, through ^{7}Be fallout technique.

MATERIALS AND METHODS:

Location of the study area

The Sehoul is located in the North west of Morocco between the Mamora forest in the north and the Grou valley in the south West. Its area is about 35100 ha (**Figure1**). Despite its location in the more favorable parts of Morocco in terms of climatic conditions, it consists of marginal land with a high poverty and important indicators of degradation. Land degradation is related to both natural factors (vulnerability) and to human factors (poverty, mismanagement). The study area is subjected to intense events of rainfall which cause soil erosion and deteriorate soil fertility.

The investigations reported in this work focused on a reference site and three agricultural fields representing the applied agricultural practices: Vineyard as MC, Barley/Wheat as (CCR), and Bean/Wheat as LCR were investigated. First field (MC) is Vineyard monoculture occupies about 0.33 ha and a slope of 10%, The second one (CCR) is cultivated with Barley in 2009 and with wheat in 2010, its surface is about 0.81 and a slope of 10%. The third one LCR, with a surface of about 0.12 ha and a slope of 11%, is cultivated with Bean in 2009 and wheat in 2010.

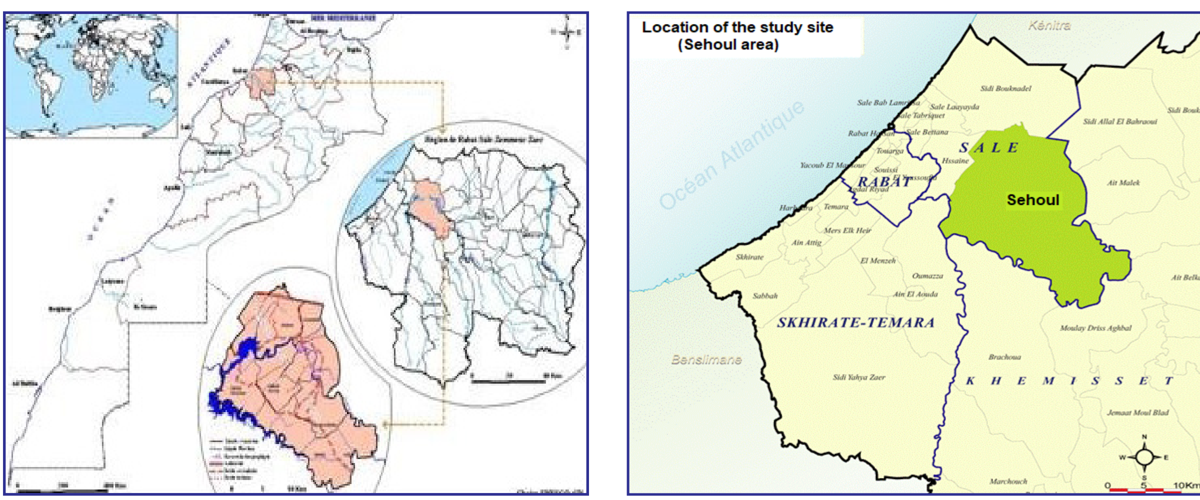


Fig. (1): Location of Sehoul area.

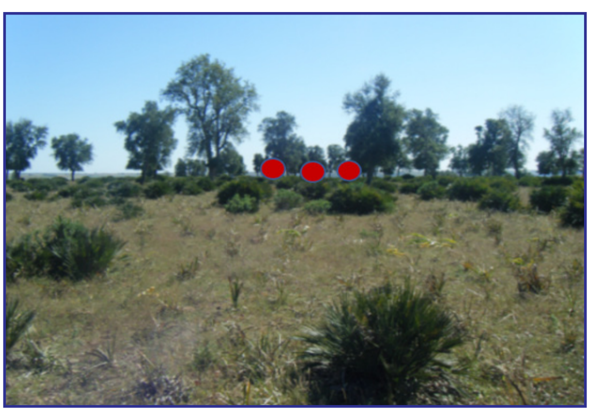
The climate in this region is classified as hot summer Mediterranean (Csa) according to Koppen-Geiger classification **(Kottek *et al.*, 2006)**. Rainfall regime is irregular with a dry period in summer and a wet period in autumn and spring. The mean annual precipitation is of about 527 mm. The amount of rainfall events during the growing season 2009 and 2010 were 664 and 929 mm respectively.

The soils on the plateau surface are very fragile-Fersialitic (red) soil having a texture of sandy loam with stones. The recent human pressure on the land and forest leads to the removal of the superficial sand layer and the formation of new dunes. The organic layer is rapidly destroyed during the dry years and the re-stabilization is very difficult to obtain. Cereals represent about 71% of the cultivated area. Dominant cereal crops are Barley, Wheat and Maize. Fruit plantations come in second with 7.5%, 4 % for fodder crops, 2 % for vegetables crops, 1.5% legumes and the rest of area, 14% is left bare.

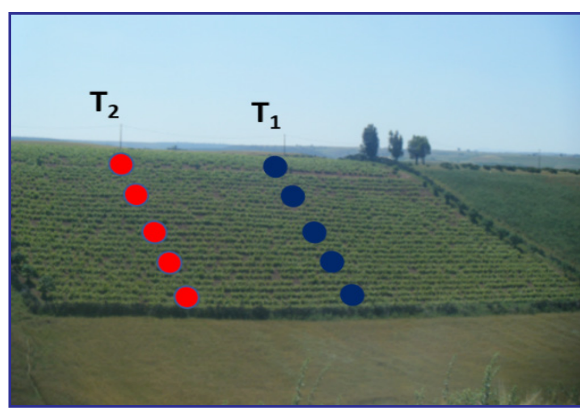
Table (1) : *Cropping pattern in Sehoul region.*

Cropping pattern	Area in ha	Occupation %
Cereals	14300	71
legumes	300	1.5
vegetables crops	400	2
fodder crops	800	4
fruit plantations	1500	7.5
Bare soil	2800	14
Total	20100	100

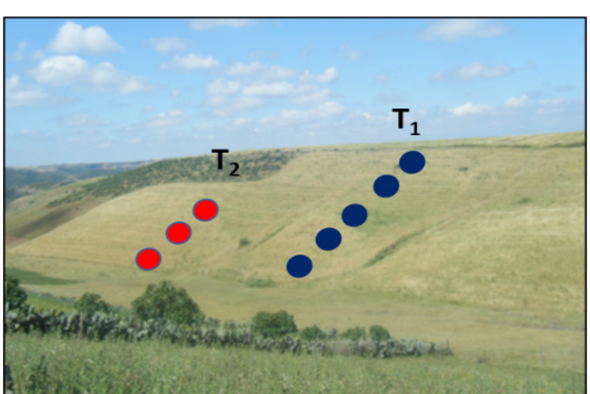
The choice of a suitable reference site is important. The reference site should have received the same annual precipitation and have the same geomorphological parameters as the studied fields. The reference site was selected in the upstream area at a low dense forest located at 600 m from the studied agricultural fields. These studied fields are mentioned in **Figure 2**.



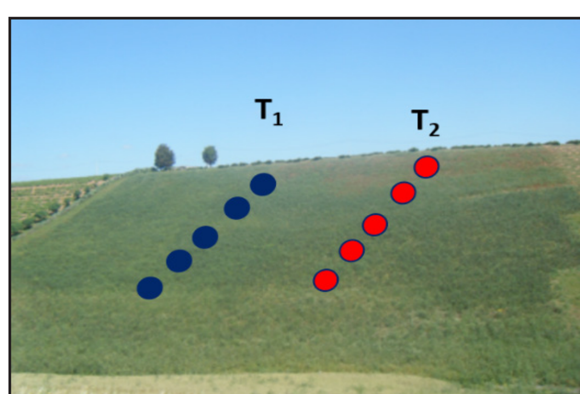
A) Reference site



B) Vineyard field



C) Barley/ Wheat field



D) Bean/Wheat field

Fig. (2): The reference site (A) and the investigated agricultural fields B, C, D.

SAMPLING METHODOLOGY

Reference site

The samples were taken using a cylindrical tube (ca. diameter: 15 cm and length: 5 cm) inserted on the soil to a depth of 5 cm to ensure that all ^{7}Be is retained. Eight reference samples were collected (R_{11}, R_{12}, R_{13}, R_{14}, R_{15}, R_{16}, R_{17}, R_{18}) inside two circles of 20 m and 40 m in diameter in the undisturbed site. To obtain information concerning the depth distribution of ^{7}Be concentration, the soil core S_{17} was divided into depth incremental subsamples of 5 mm each.

Study sites

The sampling procedure is based on the transect approach; this consists of a sequence of samples collected along the axis of the greatest slope from the upslope to downslope boundary. Two sample campaigns were performed during growing season of 2009 and 2010. During the sampling campaign in 2009 and 2010 two parallel transects (T_1 and T_2) across each field were selected, each transect consisted of five successive samples located 20 m apart from each other. However, when we sampled the field of Barley/Wheat rotation, five samples were collected along the first transect (T_1) and three samples were collected from the second transect (T_2) in 2009 and only the first transect (T_1) was sampled in 2010 due to limited accessibility to the field imposed by the owner framer however we have increased the number of samples in this transect to seven soil cores and six to seven cores on other transects too.

Preparing soil samples and measurements of ^{7}Be activity concentration

The soil samples were prepared for gamma spectroscopy measurements according to the protocol proposed by **Walling and Quine,1993; Pennock and Appleby, 2002**. Each individual sample was air dried at 80 °C for 24 hours then it was ground and sieved to ≤2mm. The core and depth incremental samples were homogenized. The mass of the soil samples prepared is around 670 g for the Marinelli Baker with a volume of 500 ml and around 200 g for the cylindrical geometry with a volume of 150 ml.

The activity concentration of ^{7}Be for each individual sample was measured by gamma spectrometry technique using two similar high purity germanium (HPGe) coaxial p-type detectors (Canberra) with a relative efficiency of 30% and energy resolution of 1.8 keV at 1332 keV coupled to a multichannel analyzer system. Both detectors were shielded with Lead to minimize background. The ^{7}Be activities were determined from the net area under full energy peak in the spectrum at 477.6 keV with counting time was set to 86400 seconds at a precision lower than ca. 10% at the 95% level of confidence for all measurements. No correction for self-attenuation of gamma ray 477.5 keV was applied. We assumed it to be negligible compared to the statistical counting error. A previous experimental work done using point sources (individual and/or multi-gamma) in order to determine self-attenuation correction factors for different matrixes and different energies including soil and water allowed to observe a little difference between soil and water matrixes for such range of energies (> 300 keV). The use of certified mixed sources liquid solution and IAEA reference materials allowed us to calibrate the detection system efficiency for each counting geometry. The standard used is a liquid mixed gamma sources containing artificial nuclides composed of the following radionuclides: ^{241}Am, ^{109}Cd, ^{57}Co, ^{139}Ce, ^{203}Hg, ^{51}Cr, ^{137}Cs, ^{54}Mn and ^{60}Co. The experimental procedure was based on the calibration of the detector by the multi-gamma source and the determination of the efficiency corresponding to ^{7}Be gamma energy of 477.6 keV by a polynomial fitting of the function: log (efficiency) versus log (energy). Soil reference material of IAEA (No. IAEA 327) was served to validate the calibration and the fit by comparing the efficiency experimental and fitted values for different energies of this reference materials (e.g., ^{137}Cs, ^{228}Ac, ^{214}Bi, ^{40}K…). Unfortunately, there is no IAEA reference material containing the ^{7}Be, due to its very short half-life (53.3 days) for a direct comparison.

The measured activities were decay corrected to the time of the sample collection using the following general expression (**Murray *et al.*, 1987**):

$$C = \frac{N\lambda t_c e^{\lambda t_0}}{\varepsilon I_\gamma M t_c (1 - e^{\lambda t_c})} \qquad Eq.1$$

where:

A = activity or concentration of ^{7}Be in Bq kg^{-1} at the sampling;

N = net peak area;

λ = decay constant ($\ln 2/t_{1/2}$), $t_{1/2}$ for ^{7}Be is 53.3 days;

tc = counting time;

t_0 = decay time (the difference between sampling and starting the measurement);

M = mass of the soil sample (kg);

ε = absolute efficiency;

Iγ = emission probability (10.44% for ^{7}Be).

Conversion of ^{7}Be inventories in erosion rates

Equations 2 and 3 can be used to convert the ^{7}Be activity concentration (Bq kg^{-1}) into the total areal activity or inventory (Bq m^{-2}) according to the following equations:

$$A_s = \frac{CM_t}{S} \qquad Eq.2$$

where:

C = activity of the analyzed sub-sample of the core sample (Bq kg^{-1});

M_t = total mass of the whole core (kg);

S = area of the horizontal core cross section (m^2).

For the depth increment samples, the areal activity of ^{7}Be is expressed as:

$$A_s = \frac{1}{S}\sum_i M_{Ti} C_i \qquad Eq.3$$

where:

C_i = activity of the i^{th} sub-sample depth increment (Bq kg^{-1});

M_{Ti}= total mass of the i^{th} sample depth increment (kg);

S = area of the horizontal core cross (m^2).

At the reference site where the soil is undisturbed, it's supposed that the ^{7}Be concentration C(x) (Bq kg^{-1}) has an exponential decline with soil mass depth x (kg m^{-2}). Soil mass depth is used to measure depth in soil and is obtained by multiplying soil bulk density and the depth of soil layer. Therefore, the activity concentration at a certain depth C(x) can be expressed as in equation (4):

$$C(x) = C(0)e^{\left(\frac{-x}{h_0}\right)} \qquad Eq.4$$

where C(0) is the activity concentration on the soil surface. The parameter h_0 is the relaxation mass depth, which 63.2% of the ^{7}Be inventory can be found and is used to calculate the ^{7}Be penetration into soil and it relates ^{7}Be activity (Bq kg^{-1}) with cumulative mass depth (kg m^{-2}).

The conversion of ^{7}Be inventories into erosion or deposition values in kg m^{-2}, was performed using the Profile Distribution Model (PDM) which was proposed by **Walling and He (1999) and Blake *et al.*, 1999** to quantify the differences in ^{7}Be inventory between the reference sites and study sites. This model is applied in the case of the collection of the soil samples for measuring ^{7}Be after the cultivation period and rainfall falling.

Taking into account the distribution defined by Eq. (4), Changes in the sample site inventories can be represented as:

$$A(h) = \int_h^\infty C(x)dx = A_{ref}\, e^{\left(\frac{-h}{h_0}\right)} \qquad Eq.5$$

Erosion rates (kg m^{-2}) can be estimated by comparing the ^{7}Be inventories at the sample site, A (kg m^{-2}), to the reference inventory, A_{ref} (kg m^{-2}). Where a mass of soil has been lost (h) (kg m^{-2}, negative).

$$h = h_0 \ln\left(\frac{A}{A_{ref}}\right) \qquad Eq.6$$

Deposition of material is reflected in an excess of ^{7}Be inventory at the sample site with respect to the reference site. The depth of deposition, (h′) (kg.m^{-2}, positive) can be calculated as:

$$h' = A - A_{ref}/C_d \qquad Eq.7$$

Where C_d (Bq kg^{-1}) is the mean activity concentration of ^{7}Be in the deposited sediment.

The Profile Distribution Model (PDM) was solved using a standard add-in within Microsoft Excel software (**Zapata, 2002**) for converting ^{7}Be inventories to soil **Results:**

Depth distribution of ^{7}Be activity concentration

Figure 3 presents the depth distribution of ^{7}Be activity concentration for the reference site. The ^{7}Be activity concentration profile for the identified reference site shows a sharp decrease of ^{7}Be activity concentration with increasing mass depth. The relaxation mass depth which 63.2% of the ^{7}Be inventory is presented was found within the upper 6.1 kg m^{-2}. This exponential distribution is a typical for an undisturbed site and has been confirmed by many field experiments similar to that reported by other researchers (**Walling *et al.*, 1999; Wallbrink and Murray, 1993; Zapata, 2002, Kassab *et al.*, 2022b**). This provides a confirmation on validating the chosen reference site for the studied area.

Inventory of the reference site

The ^{7}Be inventories obtained for the eight soil cores collected from the reference site are given in **Table 2**. The mean ^{7}Be inventory calculated for the soil cores sampled from reference site was found of 315.43 Bq m^{-2} with a relative standard deviation of 18%, which further confirms the reference site validity. Nevertheless, the slight variation noted for reference ^{7}Be inventories can be explain by the soil heterogeneity such as soil microreliefs, percentage of clay particles in soil, vegetation density and biological activity.

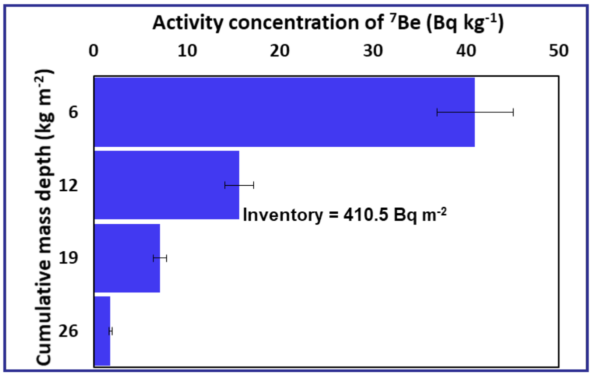


Fig. (3): The ^{7}Be depth distribution of reference site.

Table (2) : *Activity concentration and inventory of ^{7}Be measured at reference site.*

Sampling point	R_{11}	R_{12}	R_{13}	R_{14}	R_{15}	R_{16}	R_{17}*	R_{18}	Mean value	STD*	CV** (%)
Activity (Bq kg^{-1})	7.47	5.25	7.74	3.94	5.65	7.57	9.43	7.78	6.85	1.8	25.7
Inventory (Bq m^{-2})	283.7	274.6	345.4	320.4	278.7	235	410.5	374.9	315.43	58.53	18

**Sectioned core* ***STD refers to standard deviation* ****CV refers to coefficient of variation*

Inventory of the studied sites

For the agricultural studied sites CCR, MC and LCR, the ^{7}Be inventories measured for the sampling points collected at each transect, for the two studied years 2009 and 2010, are presented in (**Figure 4**).

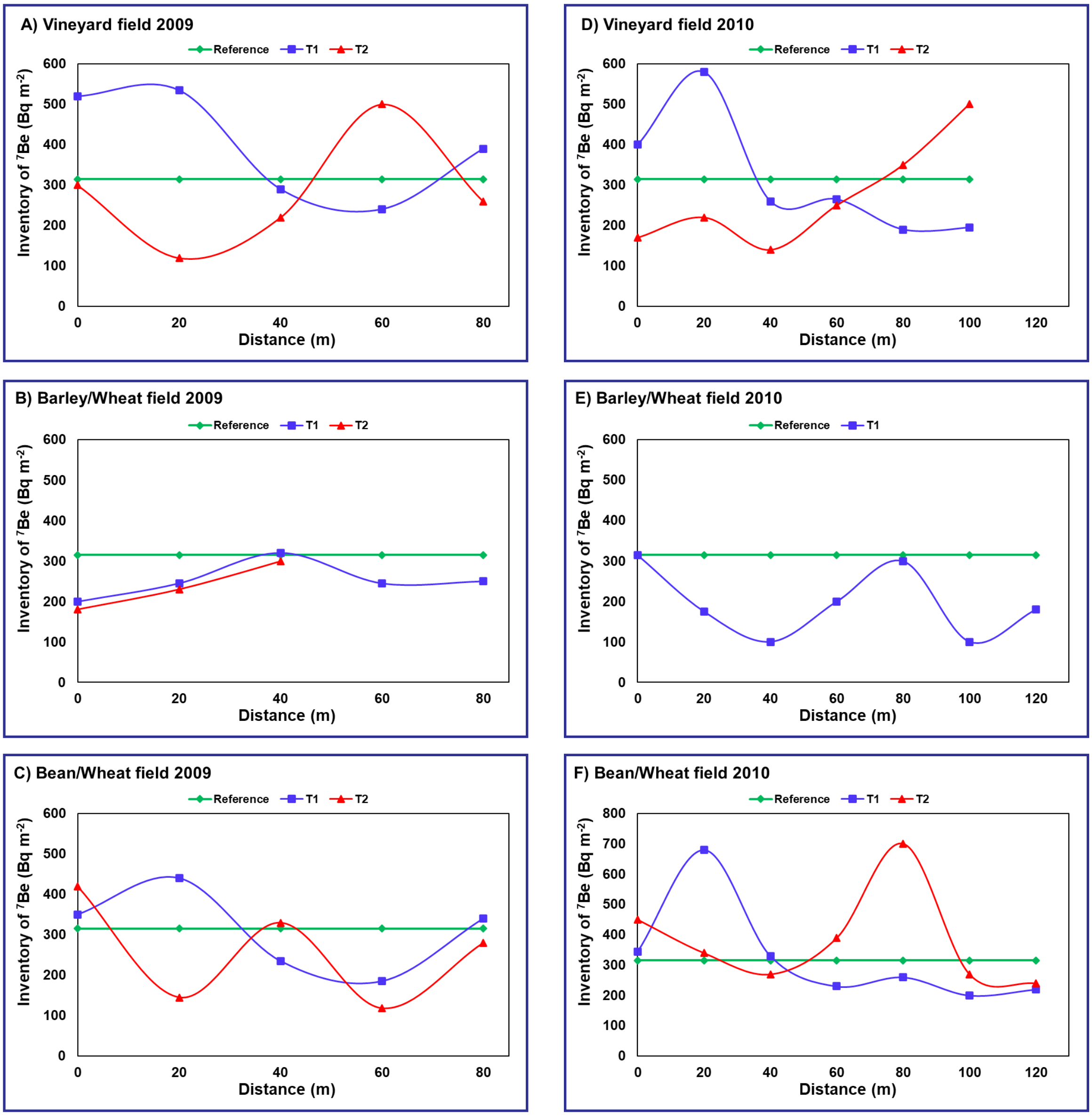


Fig. (4): Spatial distribution of ^{7}Be inventory for three agricultural fields in 2009 and 2010.

For the year 2009 (**Figure 4 A, B, C**), the results show a difference in spatial distribution of ^{7}Be inventories compared to the reference value, from the upslope to the bottom along the transects, for each site MC (Vineyard field) and LCR (Bean/Wheat rotation) which can be explain by longitudinal and lateral soil particle's distribution due to the slope topography (slope concavity and/or convexity) (see **Figure 2**). The lowest and highest ^{7}Be inventories from the reference value were noted for the LCR field. Whereas for the CCR (Barley/Wheat rotation), the ^{7}Be inventories show the same inventory distribution in the sampled transects, with only a decrease in ^{7}Be inventory compared to the reference value, indicating that only a soil loss occurred at this site. In this site only 3 cores were collected from the second transect because there was no more cultivation from the third point.

For the year 2010, (**Figure 4 D, E, F**) more samples were extracted from each transect in all studied sites to have more details and information's on soil distribution through ^{7}Be inventories distribution. The obtained measured inventories illustrate similar trend of ^{7}Be inventories spatial distribution to that found in 2009, nevertheless the year 2010 was marked by heavy precipitation of about 929 mm compared to 2009 where rainfall was about 664 mm, despite crop change. This confirms the role of site topography in soil particle distribution. However, the lowest ^{7}Be inventory from reference value was noted for CCR (Barley/Wheat) site indicating important soil loss, while vineyard and LCR site showed less decrease of ^{7}Be inventories from the reference value highlighting less soil loss. Also, only soil erosion was noted for CCR field for 2010 as for 2009.Although the comparison of measured inventories with the local reference value provides useful qualitative information on soil loss and gain, the quantitative assessments of soil erosion and deposition still necessary to determine which crop system is effectiveness for Sehoul region.

Table (3) summaries the gross erosion rate, gross deposition rate and net erosion rate in the three studied agricultural fields for two years 2009 and 2010 using profile distribution model.

Table (3) : *The erosion and deposition rates of soil (t ha^{-1}), estimated in agricultural fields.*

Erosion / deposition	2009			2010		
	Vineyard (MC)	Wheat (CCR)	Bean (LCR)	Vineyard (MC)	Barley (CCR)	Wheat (LCR)
Gross erosion rate	-5	-6.8	-7.6	-7.4	-13.9	-4.2
Gross deposition rate	5.9	0.0	1.8	4.1	0.0	5.9
Net erosion rate	0.9	-6.7	-5.8	-3.3	-13.9	1.7

N.B. Negative values refer to erosion and positive values refer to deposition

The results showed a negative sediment balance, more erosion than sedimentation for the 3 studied fields during the 2 years, despite the difference of the annual precipitation of the two studied years, about 664 mm for 2009 and 929 mm for 2010.

The minimum rate of net soil loss was found, for the agricultural practice of the vineyard for the year 2009, of about 0.9 t ha^{-1} which experienced an increase with the heavy rainfall of 2010 and reached 3 t ha^{-1}. For the LCR crop rotation, even if the mean annual rainfall amount associated with 2010 was higher than that corresponding to 2009, the erosion rate has decreased and only deposition of 1.7 t ha^{-1} was noted, no erosion. This highlights a resilience to heavy rainfall as a results of soil conservation due to legume/cereal rotation practice adopted during two years. In contrast, the field cultivated with wheat/barely rotation for the two consecutive years, showed significant soil erosion of 6.7 t ha^{-1} for the year 2009 and which was accentuated by the heavy rains that occurred in 2010.

DISCUSSIONS

In general, the obtained results of this work highlighted the capability of ^{7}Be technique in soil redistribution processes caused by rain event and the magnitude of the relative soil loss compared to an undisturbed reference site. The soil loss estimated values was affected by the land use (crop rotation). Different plant covers afforded different degrees of protection so that human influences, by determining land use, can exert much influence on erosion rates (**Morgan 1995**). From the obtained estimations of soil erosion based on ^{7}Be measurements we can notice that Bean/Wheat rotation practice allowed the soil to be protected particularly in the second year of investigation and when more precipitations fallen in 2010. This crop technique was introduced in the sehoul region as conservative practice; it occupies 1.5% of the total agricultural Sehoul area. The main advantage of this rotation is the enhancement of soil fertility through the fixation of nitrogen in the soil **(Keith *et al.,* 2006)** and increasing organic matter content in soil which leads to decrease the soil loss (**David *et al.,* 2004**). That was confirmed and in agreement with ^{7}Be measurements.

The vineyard monoculture showed the least erosive technique in Sehoul area in 2009 and mainly due to the leave interception of rainfall, however when precipitation has increased in 2010 more erosion was observed. This behavior was reported in many literatures due to use of tractors in vineyard farms which enhances the micro-topographical changes (**Ferrero *et al.,* 2005**). Additionally, the flow path and subsequent connectivity processes contributes to soil erosion occurrence **(Arnaez *et al.,* 2007; Quiquerez *et al.,* 2008)**. Therefore, the use of soil erosion control measures that protect uncovered soils and conserve grape and wine quality can be considered a priority (**Paroissien *et al.,* 2010)**

The worst land use practise was the cereal/cereal rotation (CCR) i.e., Wheat/Barely. It showed the highest values of soil loss and contributes to increased soil degradation. Within the two growing season the estimated value of soil loss in (CCR) has doubled and it is mainly related to the continuous disturbance of soil surface due to tillage practices which make the soil more vulnerable to erosion by rain. Cereal/cereal rotation (CCR) occupies about 71% of the total agricultural Sehoul lands, it is the widely used crop system in Sehoul catchment area and should be substituted by other sustainable agricultural practices.

CONCLUSION

The present research is the first approach of studying crop technique efficiency in Sehoul region through the use of ^{7}Be radioisotope inventories. Indeed, sampling by using several transect has allowed to highlight the spatial distribution of ^{7}Be and so on the soil particles behaviour associated with the rain events for 2009 and 2010. The assessment of soil erosion amount during two consecutive years has permitted to study the effectiveness of the implemented crops in Sehoul watershed. The results obtained for the three crop systems through the estimation of soil loss, by using ^{7}Be measurements for 2009 and 2010, showed that cereal/legumes rotation is adequate sustainable agricultural practice for Sehoul watershed since it allowed to mitigate soil from erosion and reduce the rate of erosion from 5.8 t ha^{-1} in 2009 to deposition of 1.7 t ha^{-1} in 2010, despite the heavy precipitations occurred in 2010. Vineyard monoculture needs more conservation measures to combat water erosion. Whereas, cereal/cereal rotation is causing serious soil loss, the greater the intensity and duration of a rainstorm, the higher the erosion potential.

This research work allowed us to confirm the potential of the ^{7}Be technique to study the efficiency of agricultural techniques in Morocco, particularly in the Sehoul region. It is in fact an excellent sediment tracer and innovator tool for evaluating effectiveness of soil crops through assessing soil erosion associated with individual events or short periods

ACKNOWLEDGEMENTS

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