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The ^{7}Be profiles in the undisturbed soil used for reference site to estimate the soil erosion

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Abstract. The cosmogenic radionuclide ^{7}Be is increasingly used to obtain information on event-related soil erosion rates within agricultural landscapes. In this study, we select two undisturbed and flat areas to calculate the reference inventory and relaxation mass depth by using ^{7}Be technique to document short-term erosion. Our results showed that the depth distribution of ^{7}Be in undisturbed soil profiles was 1.0 cm in sites S02 and S03; the initial activities were 31.6 and 38.8 Bq.kg^{-1}, respectively. The relaxation mass depths were 5.4 and 7.2 kg.m^{-2} and the measured reference ^{7}Be inventories were 71 and 110 Bq.m^{-2} for sites S02 and S03, respectively. The difference values of the relaxation mass depth and the reference inventory of both sites implied that for determining a short term soil erosion using ^{7}Be, the reference site was suggested to be selected as close as possible to the study site.

1. Introduction

Some agricultural practices such as burning of stubble and crop residues after harvest and subsequent ploughing and disc harrowing for seed bed preparation leave large areas of bare soil have increased the soil erosion problem that relating to the reduction in soil productivity and to the off-site effects of eroded sediments such as transportation of the sediment-associated nutrients and contaminants (e.g. agricultural pesticides) through terrestrial and aquatic ecosystems [1-3]. Therefore, the reliable information on rates of soil loss is important for an improved understanding of sediment transfer and storage in catchments and river basins to provide a basis for sustainable soil management. The environmental radionuclides ^{137}Cs ($T_{1/2}$ = 30 years) and unsupported ^{210}Pb ($T_{1/2}$ = 22 years) are widely used to document rates of soil redistribution on agricultural land, but both these radionuclides have provided the retrospective estimates in the medium-term (i.e. ca. 50 years for ^{137}Cs and up to 100 years for unsupported ^{210}Pb). The obtained values from both radionuclides are the average rates taking account of inter-annual variability in the magnitude and frequency of erosional events. If the magnitudes of soil loss associated with individual events or periods characterized by specific land use conditions are required, the short-lived radionuclide ^{7}Be is used to calculate the soil erosion rates. This paper reports a preliminary investigation of undisturbed and flat areas aimed at exploring the potential for using ^{7}Be measurements as the reference inventory and relaxation mass depth to document the short-term events of soil erosion.

2. **Methodology**

2.1 Background and initial depth distribution of the beryllium-7 in the soil

^7Be is produced by cosmic-rays spallation reactions in the atmosphere. These reactions occur primarily in the stratosphere and upper troposphere, where charged particles (alpha particles, electrons and protons) induce nuclear reactions with oxygen and nitrogen atoms. The ^7Be attaches to airborne particles and its deposition is continuously delivered to the earth's surface by wet and dry fallout [2, 4-6]. Although it is quickly sequestered to the Be^{2+} ion by slightly acid rainfall, its ion is rapidly and strongly fixed onto the clay minerals in the soil [2, 7]. Therefore, cosmogenic ^7Be has been widely used as a tracer to document both the magnitudes and the spatial patterns associated with short-term or event based soil redistribution on agricultural land [1-2, 8]. The ^7Be technique is, principally, based on the comparison of ^7Be inventory (Bq.m^{-2}) between sampling sites and reference site. The reference site is selected from undisturbed area located near sampling sites. The ^7Be inventory for sampling site is depleted relative to the reference inventory that can be referred to occurring erosive processes, whereas areas of deposition can be located by increased inventories [1-2, 8].

There are three key assumptions for using ^7Be measurements to estimate both the soil erosion and sedimentation rates [1-2, 8]. The deposition of ^7Be fallout from atmosphere to the ground surface is, first, spatially uniform. Secondly, preexisting ^7Be in the surface soil in study area is uniformly distributed across the area. Finally, the ^7Be deposited during event is rapidly and strongly absorbed in couple centimeters of surface soil and can be mobilized by erosion. From these assumptions, it can be assumed that the initial vertical distribution of the ^7Be activity $C(x)$, (Bq.kg^{-1}) within the soil will be characterized by an exponential decrease with mass depth x, kg.m^{-2}[1-2]. The sample model to estimate the soil erosion and sedimentation rates is described below,

$$C(x) = C(0)\exp(-x/h_o) \tag{1}$$

where $C(0)$ is the initial activity of the surface soil (at $x = 0$) and h_o, kg.m^{-2}, is the relaxation mass depth.

The reference inventory of ^7Be, A_{ref}, Bq.m^{-2}, is defined as the initial total areal activity at an uneroded stable site or reference site in the study area:

$$A_{ref} = A(0) = \int_0^\infty C(x)dx = h_o C(0) \tag{2}$$

The areal activity of ^7Be below depth x, $A(x)$, Bq.m^{-2}, for the initial distribution is therefore:

$$A(x) = \int_x^\infty C(x)dx = A_{ref}\exp(-x/h_o) \tag{3}$$

The relaxation mass depth describes the shape of the initial depth distribution of both the activity as shown in Eq. (1) and areal activity as shown in Eq. (3) in the soil.

By measuring the activity of ^7Be, C, in different depth increments of soil collected from the reference site and establishing the mass depth of each depth increment, the values of $A(x)$ for corresponding mass depths x down the reference profile can be calculated. Logarithmically transforming Eq. (3), h_o and the reference inventory A_{ref} can be deduced from a linear regression between $ln[A(x)]$ and x.

2.2 *Study site*

Atmospheric deposition fluxes of ^7Be in the study areas, the fallout samples during December, 2012 to December, 2013 for periods from 1 to 31 days depending on the frequency of rain were collected at the top roof of the Physics building called S01 site (7^{o}00'24.6" N, 100^{o}29'57.8" E) where is the control site to estimate the running inventory of ^{7}Be. Two sampling sites for rain water samples were at selected reference sites 7^{o}00'30.9" N, 100^{o}30'22.0" E (S02) and 6^{o}59'32.1" N, 100^{o}33'04.8" E (S03). Meteorological data were provided by the Thai Meteorological Department at the Songkhla Meteorological station (WMO Index: 568501/48568, located at 7^{o}12'14" N, 100^{o}36'11" E). Rain water samples were collected after rainfall event. The water sample was filtered through the MnO_2-fiber (5 g) which was in the cylinder of 15 cm long and 1.8 cm inner diameter.

The climate of the Songkhla province, Thailand is controlled by tropical monsoons that consist of the southwest (May – October) and northeast (October – February) monsoons. There are generally two seasons – the rainy season and dry season. The rainy season is influenced by the southwest monsoon (May – September) that brought the moist and warm air from the Indian Ocean whereas the northeast monsoon (October – January), brought the moist air from the Gulf of Thailand.

a) b)

Figure. 1 Photographs showing **a)** soil core sampling; **b)** cutting the cover grasses

Soil samples were collected from two selected reference sites S02 and S03 in the U-Tapao subcatchment, Songkhla province, Southern Thailand. Using a hand-operated corer equipped with the PVC pipe (8.5 cm internal diameter, 20 cm length), 8 soil cores were collected from two selected reference sites S02 and S03 on January 10, 2014. Figure. 1 shows the soil core sampling and cutting the cover grasses. All the soil cores were kept vertically and returned to the laboratory, and then sliced at 0.5 cm intervals through its depth using the hand-held extruder. All the cut samples were dried at 105 °C for 24 hours by electric oven, grinded by ceramic mortar, sieved to < 2 mm fraction, homogenized, weighed and put into a polyethylene bottle.

2.3 Measurement and analyze method

Beryllium-7 activity concentrations in fallout (wet and dry) samples, soil samples and grass were determined by measuring its gamma line at 477.6 keV. The gamma-ray measurements were performed using gamma spectrometer with an HPGe detector (GC7020, Canberra Industries, USA) in a low-background cylindrical shield (Model 747, Canberra, USA). Data were accumulated in a multichannel analyzer (DSA1000, Canberra, USA) based on a personal computer. The energy resolution was 0.88 keV (FWHM) at 122 keV (^{57}Co), and 1.77 keV (FWHM) at 1332 keV (^{60}Co). The minimum counting-time for each sample was set in 40,000s. For samples having an analytical error more than 1σ, the counting-time will be added until 100,000s to provide reasonable analytical error (less than 25% or 1σ). The spectrum analysis was performed by the commercial software Genie 2000 (Canberra, USA). The absolute efficiency curve of detector used in this work was fitted from activity concentrations of discrete gamma-ray lines in the IAEA TEL 2011-03 WWOPT soil-04 sample with certified radionuclide activities, and it was used to calculate the relative efficiency of ^{7}Be at 477.7 keV. The ^{7}Be activities were corrected for decay to the sampling time on January 10, 2014.

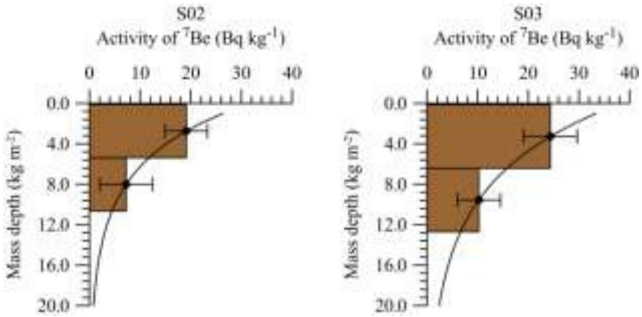

Figure 2. The depth distribution of ^{7}Be in the soil profiles within the selected reference sites.

3. Results and Discussions

The results reported in this paper were obtained from the selected reference sites (S02 and S03) where located in the undisturbed, non-tilled areas at the U-Tapao subcatchment, Songkhla province, Southern Thailand. Our results show that the depth distribution of ^{7}Be in undisturbed soil profiles is 1.0 cm in both sites (S02 and S03), the initial activities are 31.6 and 38.8 Bq.kg^{-1} for S02 and S03 sites, respectively. The ^{7}Be activities for both locations declined exponentially with mass depth as shown in Figure 2. Following from Eq.(1), the relaxation mass depths were, therefore, calculated from linear regression between $ln[C(x)]$ and x. These obtained results are 5.4 and 7.2 kg.m^{-2} for S02 and S03 sites, respectively.

The measured reference inventories of ^{7}Be in soil profiles are 71 and 110 Bq.m^{-2} for S02 and S03 sites, respectively. The calculated reference inventories from Eq. (2) are 170 and 279 Bq.m^{-2} for sites S02 and S03, respectively. Both important parameters, relaxation mass depth and reference inventory, can be used to estimate the magnitudes of soil loss or deposition. The soil mass eroded per unit area, R, kg.m^{-2}, or soil erosion rate as provided from Blake et al. [1] can be calculated by using both values as:

$$R = h_o \ln\left[A_{ref} / A\right] \tag{4}$$

Moreover, the magnitude of deposited sediment rate, R', kg.m^{-2}, can be calculated by:

$$R' = \left(A' - A_{ref}\right) / C_d \tag{5}$$

when A', Bq.m^{-2}, is the areal activity of ^{7}Be at a sampling point located in sediment deposition zone, C_d is the mean ^{7}Be activity of deposited sediment that can be estimate by

$$C_d = \int_S C_e R dS \Big/ \int_S R dS \tag{6}$$

when C_e, Bq.kg^{-1}, is the weighted mean ^{7}Be activity of mobilized sediment from eroding area S, m^{-2}, which can be:

$$C_e = (A_{ref} - A)/R = A_{ref}\left[1 - \exp(-R/h_o)\right]/R \tag{7}$$

From procedure outlined above, the h_o and A_{ref} are crucial important for calculating the magnitudes of soil erosion and deposition rates at sampling points for study area. The relaxation mass depths and ^{7}Be inventories in the soil obtained from selected reference sites are different because the atmospheric depositional fluxes of ^{7}Be are controlled by several factors depending on location, precipitation, the cover crops etc. Lohaiza et al. reported the monthly relaxation mass depths and inventory of ^{7}Be from one reference site changing with season, the maximum value in heavy rain period and low value in dry period [7]. Moreover, the relaxation mass depths in some locations where selected reference site are significantly higher than that in others. Therefore, the running atmospheric deposition flux of ^{7}Be and the ^{7}Be activity in the covered grasses were used to compare with the inventory in soil for the reference study site.

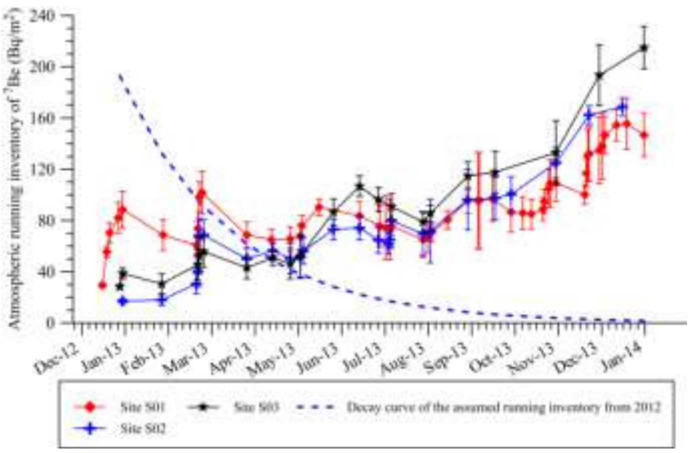

Figure 3. Atmospheric running inventory of ^{7}Be collected from S01, S02 and S03 sites.

In this study, the atmospheric depositional fluxes of ^{7}Be have been decay-corrected to the collecting time of rainfall sample, and the results are shown in Figure 3. In order to calculate the atmospheric deposition running inventory of ^{7}Be following Zhu and Olsen [9], the calculated running inventory values range 29 ± 1 to 156 ± 14 Bq.m^{-2}, with an average value of 92.2 Bq.m^{-2} for site S01, 2.0 ± 0.5 to 96 ± 12 Bq.m^{-2}, with an average value of 19.6 Bq.m^{-2} for site S02, and 2.9 ± 1 to 103 ± 15 Bq.m^{-2}, with an average value of 27.1 Bq.m^{-2} for S03. The estimated ^{7}Be running inventories at the time of sediment sampling are 156 ± 20 Bq.m^{-2}, 169 ± 7 Bq.m^{-2} and 215 ± 17 Bq.m^{-2} for S01, S02 and S03, respectively. Atmospheric running inventories for the selected reference sites S02 and S03 are shown in the Table 1 and Figure 4.

Table 1. ^{7}Be inventories in soil cores, areal activities in cover grasses and atmospheric running inventories which were corrected to the soil sampling time on January 10, 2014.

Type/Location	S02	S03
Measured sediment inventory (Bq.m^{-2})	71 ± 18	110 ± 26
Areal activity in grasses (Bq.m^{-2})	112 ± 9	108 ± 9
Atmospheric running inventory (Bq.m^{-2})	169 ± 7	215 ± 17

The measured ^{7}Be inventories in soil cores of 71 ± 18 and 110 ± 26 Bq.m^{-2} were stacked with the areal activities in cover grasses of 112 ± 9 and 108 ± 9 Bq.m^{-2} for the selected reference sites S02 and S03, respectively. The atmospheric running inventories are similar to the stacked activities between the areal activities in cover grasses and the measured ^{7}Be inventories in soil cores for both sites S02 and S03 as shown in Figure 4. The relaxation mass depths and the reference inventories of both selected reference sites showed the different values which had been influenced from the different soil types and the different atmospheric depositions of ^{7}Be. Therefore, if this method is used to determine the short term soil erosion, the reference site is suggested to be as close as possible to the study area.

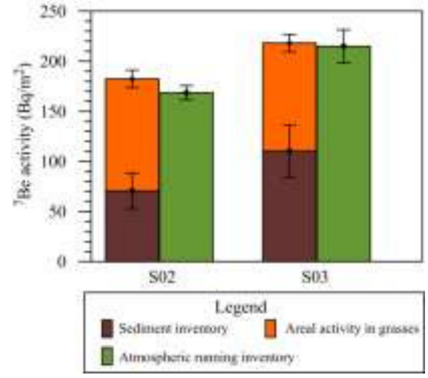

Figure 4. The bar charts comparing the atmospheric running inventory and the stacked columns between measured sediment inventory and areal activity in grasses.

Although, the calculated reference inventories, 170 and 279 Bq.m^{-2}, are larger than the measured inventories. The measured inventories in soil cores, 71 ± 18 and 110 ± 26 Bq.m^{-2} for both sites S02 and S03, may be used as the reference inventories, A_{ref}, in the model to calculate the soil erosion rates in study area. This is in fact the calculated reference inventories are not possible to be larger than the atmospheric running inventory. This problem may occur due to the thicker section of soil cores. In the future work, the thin sliced section of soil cores will be made, because there will be more than two points in the ^{7}Be profiles with mass depth to estimate the calculated reference inventory and relaxation mass depth.

4. Conclusions

This preliminary study is successful to detect ^{7}Be in the soil and atmospheric deposition in the South of Thailand located near equatorial zone where is known that very low ^{7}Be activity and the ^{7}Be measurement in soil can be used to estimate important parameters (relaxation mass depth and reference inventory) for approached model of the soil erosion. Further work, we will investigate the magnitudes of both soil erosion and deposition obtained from the ^{7}Be measurement technique in this study area.

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