Atmospheric Environment 77 (2013) 178–184

Contents lists available at SciVerse ScienceDirect

Atmospheric Environment

journal homepage: www.elsevier.com/locate/atmosenv

Beryllium-7 atmospheric deposition and soil inventory on the northern Loess Plateau of China

Fengbao Zhang [a,b], Bo Zhang [b], Mingyi Yang [a,b,*]

[a] State Key Laboratory of Soil Erosion and Dryland Farming on the Loess Plateau, Institute of Soil and Water Conservation, Northwest A&F University, Yangling, Shaanxi 712100, China

[b] Institute of Soil and Water Conservation, Chinese Academy of Science and Ministry of Water Resources, Yangling, Shaanxi 712100, China

HIGHLIGHTS

- ^{7}Be concentrations in rainfall were artificially high due to ^{7}Be dry deposition.
- ^{7}Be deposition input showed the highest in summer and the lowest in winter.
- ^{7}Be inventories in undisturbed soil were obviously unimodal over the year.

ARTICLE INFO

Article history:
Received 11 August 2012
Received in revised form
12 April 2013
Accepted 3 May 2013

Keywords:
Loess Plateau
^{7}Be
Deposition flux
Soil inventory

ABSTRACT

Beryllium-7 is a potentially powerful tracer of soil erosion, but information on ^{7}Be atmospheric deposition and associated soil inventories on the Loess Plateau of China is not readily available. In the study reported in this paper, we measured the ^{7}Be inventories in undisturbed soil at different sampling times on the northern Loess Plateau of China for three years, between 2010 and 2012, and estimated the ^{7}Be deposition fluxes and the daily ^{7}Be inventories in undisturbed soil. The annual ^{7}Be deposition fluxes during this period varied between 1303 ± 119 and 2222 ± 147 Bq m^{-2}, with a mean of 1759 ± 416 Bq m^{-2}. There is a marked seasonality for the ^{7}Be deposition fluxes with the maximum in summer, approximately 50% to the annual deposition flux, and the minimum in winter, approximately 5% to the annual deposition flux. Precipitation amounts can explain more than 70% of the variation in ^{7}Be deposition flux. ^{7}Be deposition in the form of dustfall, dew and frost make a significant contribution to the ^{7}Be deposition flux in the study region. The daily ^{7}Be inventories in undisturbed soil varied markedly through time and ranged between 89.2 and 941.8 Bq m^{-2} with a mean of 392 ± 210 Bq m^{-2}. They demonstrated a unimodal distribution over the year, with the highest values in August or September and the lowest in late winter or early spring.

1. Introduction

Cosmogenic ^{7}Be ($T_{1/2}$ = 53.3 d) is produced in the upper troposphere and mainly in the stratosphere as a product of the spallation reaction of oxygen and nitrogen nuclei with high-energy cosmic ray particles (Lal et al., 1958). After ^{7}Be is produced, it rapidly forms BeO or $Be(OH)_2$ by ionic reactions and becomes associated with sub-micrometre aerosol particles (Papastefanou and Ioannidou, 1995; Cho et al., 2007). Subsequently, ^{7}Be enters the marine and terrestrial environments through wet and dry deposition processes (Wallbrink and Murray, 1994; Ioannidou and Papastefanou, 2006; Doering and Akber, 2008). Many investigators (Olsen et al., 1985; Dibb, 1989; Harvey and Matthews, 1989; Todd et al., 1989; Caillet et al., 2001; Graham et al., 2003) have suggested a linear relationship between the amount of precipitation and ^{7}Be deposition flux and have shown that precipitation plays a dominant role in ^{7}Be deposition flux. Annual, seasonal and monthly variations of ^{7}Be deposition fluxes, which are determined by the ^{7}Be production rate in the atmosphere, the extent of stratospheric to tropospheric air exchange, tropospheric circulation patterns, latitude, and the efficiency of the removal of ^{7}Be by wet and dry deposition, have also been reported for many areas of the world (Narazaki et al., 2003; González-Gómez et al., 2006; Baskaran and Swarzenski, 2007; Juri Ayub et al., 2009). Upon reaching the land surface, ^{7}Be is rapidly and strongly fixed by soil particles and other ground cover and

* Corresponding author. State Key Laboratory of Soil Erosion and Dryland Farming on the Loess Plateau, Institute of Soil and Water Conservation, Northwest A&F University, No. 26 Xinong Road, Yangling District, Shaanxi Province 712100, China. Tel.: +86 (0)29 87012884; fax: +86 (0)29 87016082.
E-mail address: ymyzly@163.com (M. Yang).

1352-2310/$ – see front matter
http://dx.doi.org/10.1016/j.atmosenv.2013.05.002

activities are readily measured by gamma spectrometry (Bondietti et al., 1984; Wallbrink and Murray, 1996; Papastefanou et al., 1999; Zhang et al., 2011). ^{7}Be in bare soil is restricted to an upper surface layer of approximately 20 mm, predominantly within the first 10 mm, and it decreases exponentially with increased depth (Wallbrink and Murray, 1996; Blake et al., 1999; Walling et al., 1999; Wilson et al., 2003; Yang et al., 2006). ^{7}Be has been used successfully to document soil erosion occurring on bare soils since the 1990s in various places around the world (Wallbrink and Murray, 1993; Blake et al., 1999; Walling et al., 1999; Wilson et al., 2003; Yang et al., 2006; Sepulveda et al., 2008; Walling et al., 2009; Schuller et al., 2010).

Soil erosion is a major environmental and agricultural problem on the Loess Plateau of China. There is an urgent need to quantify amounts of soil loss and ^{7}Be measurement offer a valuable means of quantifying short-term erosion rates. For such studies, a good understanding of the local deposition flux of ^{7}Be and the temporal variation of the ^{7}Be soil inventory is necessary. However, information on ^{7}Be deposition flux and soil inventories is relatively scarce on the Loess Plateau. Although a large amount of data on ^{7}Be atmospheric deposition is available for other areas of the world (Walling, 2013), ^{7}Be deposition fluxes are site specific and strongly dependent on location, and particularly latitude and local meteorological conditions. The underlying objectives of the study reported here were to document ^{7}Be deposition fluxes and to reconstruct the temporal distribution of ^{7}Be fallout inputs and associated daily ^{7}Be inventories in undisturbed soil on the northern Loess Plateau by measuring ^{7}Be inventories in undisturbed soil at regular intervals and to examine the short-term variations and the factors that may possibly influence them. No previous publication has reported the ^{7}Be deposition fluxes for this region and this study therefore provides information on inputs of ^{7}Be to the northern Loess Plateau to add to existing databases.

2. Methods for determining ^{7}Be deposition flux

Generally, ^{7}Be deposition flux has been determined by collecting the rainfall and dry fallout for individual rainfall events or at regular intervals, recovering the ^{7}Be from the collected rainfall by chemical means, measuring the ^{7}Be activity by gamma spectrometry, and then calculating the ^{7}Be fallout input as the product of the ^{7}Be concentration in the collected rainfall and the amount of precipitation during the rainfall event or sampling interval (Wallbrink and Murray, 1994; Caillet et al., 2001). However, the chemical procedure required to separate ^{7}Be from rainfall is complex and time consuming. It is known that the ^{7}Be inventory in undisturbed soil directly reflects the ^{7}Be fallout input and is controlled by the ^{7}Be fallout input and the decay of ^{7}Be. Variations of the ^{7}Be inventory in undisturbed soil can reflect the variations of ^{7}Be fallout input. Previous investigators have also shown that undisturbed soil sites serve as effective natural repositories for atmospherically derived radionuclides and that soil inventories from such sites can be used to estimate past atmospheric fluxes (Hardy et al., 1973; Moore and Poet, 1976; Nozaki et al., 1978).Walling et al. (2009) calculated the mean ^{7}Be concentration in rainwater (C_m in Bq l^{-1}) using Eq. (1), based on measurements of the ^{7}Be inventories in undisturbed soil and records of daily rainfall. They then used this value to calculate the ^{7}Be deposition flux and reconstructed the temporal distribution of ^{7}Be fallout input during the periods between inventory measurements. Eq. (1) was expressed as:

$$C_m = \left[A_{\text{ref}}\left(T\right) - A_{\text{ref}}\left(t=0\right)\exp\left(-\lambda T\right)\right] \Big/ \int_0^T I(t)\exp[-\lambda(T-t)]\text{d}t \tag{1}$$

where A_{ref} (Bq m^{-2}) is the ^{7}Be inventory in undisturbed soil, I (l m^{-2}) is the daily rainfall, λ is the daily decay constant for ^{7}Be, and T (d) is the number of days in the study period. In this equation, Walling et al. (2009) assumed that the ^{7}Be concentration in rainwater at a given site is constant at the weekly or monthly timescale, that all the ^{7}Be fallout is delivered as wet deposition and that dry deposition can be ignored during the inter-sampling period. Walling et al. (2009) also demonstrated that it is reasonable to assume that the mean ^{7}Be concentration in rainfall remains essentially constant on the weekly or monthly timescale. However, dry deposition (dustfall, dew and frost) may be significant in semi-arid and arid regions and will influence the results obtained using this approach. Further details are provided below.

3. Study site and experimental procedures

3.1. Study site

The study site was located in the Dunshan watershed at the Ansai Research Station of Soil and Water Conservation, Chinese Academy of Science, situated within Ansai County, Shaanxi Province, on the northern Loess Plateau region of China (109°19′23″E, 36°51′30″N). The climate is warm and semi-arid. The mean annual precipitation is approximately 510 mm, most of which falls during the period July to September and causes severe soil erosion. The annual mean temperature is 8.8 °C, and the annual evaporation ranges from 1500 to 1800 mm. The soil type is Huangmian soil (Calcaric Cambisols, FAO), developed by wind deposits and characterized by a yellow colour. Dustfall occurs frequently in this region, particularly in spring and early summer.

3.2. Soil sampling and laboratory procedures

Five adjacent experimental plots with a 0° slope in the Ansai Research Station were selected as our experimental sites for sampling soil. On December 31, 2009, these plots were manually tilled to mix the upper 25 cm layer. Extraneous materials such as stones, roots or grass fragments were removed, and the surface was smoothed by replicating local cultivation practices. $A_{\text{ref}}\,(t=0)$ was assumed to be zero after tilling. To maintain the surface of these plots bare, herbicide was sprayed on to prevent the growth of vegetation during the study period. Further disturbance of the plots was prevented. Soil samples were routinely collected from April 1, 2010, to December 25, 2012. In each plot, three soil samples were collected using a scraper-plate to a depth of 2.5 cm within an area of 10×10 cm^2 and these were mixed to provide a single composite soil sample. A total of five mixed soil samples were sent back to the laboratory to measure the ^{7}Be activity on each sampling occasion. Few samples were collected in winter and early spring because of the low amount of precipitation. All soil samples were air-dried, weighed, dispersed and passed through a 1 mm sieve. The samples of sieved soil were then packed into identical plastic column-shaped boxes prior to detecting ^{7}Be activity.

Measurements of the ^{7}Be activity in soil were undertaken by gamma spectrometry using a high-resolution, low-background, low-energy, hyperpure n-type germanium coaxial r-ray detector (EG&G ORTEC, Oak Ridge, TN, USA). Further details of the ^{7}Be measurement procedure are provided by Yang et al. (2006) and Zhang et al. (2011). The measured ^{7}Be activity was always corrected to the sampling day using the decay constant. The mean inventory of the five soil samples was used to represent the ^{7}Be inventory in undisturbed soil on each sampling occasion. Statistical analyses were performed using SPSS PASW Statistics (Version 18.0) software.