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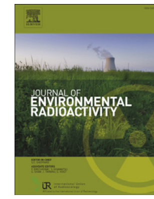

Dynamic distribution of potassium in sugarcane

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ABSTRACT

In this work the distribution of potassium in sugarcane has been studied during its growth. The soil was prepared with natural fertilizers prepared with sugarcane bagasse. For the measurement of potassium concentration in each part of the plant, gamma-ray spectrometry was used to measure gamma-rays emitted from the radioisotope ^{40}K. The concentrations of potassium in roots, stems and leaves were measured every two to three months beginning about five months after planting the sugarcane. The results show a higher concentration of potassium at the beginning of plant development and over time, there is an oscillatory behavior in this concentration in each part of the plant, reaching a lower concentration in the adult plant. To describe the evolution of potassium distribution in sugarcane we proposed a phenomenological model assuming that the potassium incorporation rate is proportional to the difference between the element concentration in the plant and a very long term equilibrium value and it is coupled to a resource-limited growth model. The proposed model succeeded in interpreting the results for the potassium distribution in stems and leaves during the sugarcane growth.

1. Introduction

Gamma-ray spectrometry is widely used in elemental analysis to identify and quantify, with relatively high precision, natural radioactive elements such as ^{40}K and the isotopes of the ^{232}Th and ^{238}U series. Gamma-ray spectrometry is a very accurate technique which allows the measurement of radionuclides present in samples with very low concentration. This technique has been applied in many scientific works in several different research areas such as agronomy, medicine, geology, etc. (UNSCEAR, 2000; Scheibel, 2006; Velasco et al., 2012; Grena et al., 2010; Cohn and Dombrowski, 1970; Maidana et al., 2009; Anjos et al., 2009; Zagatto et al., 2008; Aguiar et al., 2010; Silveira et al., 2009a, b; Matsumoto et al., 2008; Umisedo et al., 2008; Silveira et al., 2012; Conceição et al., 2009; Kohler et al., 2000). This technique is used to study, for example, effective dose transfer to human beings from naturally-occurring radioactive material (NORM) and technologically enhanced naturally-occurring radioactive material (TNORM) (UNSCEAR, 2000). In agronomy, this technique is used to follow potassium in plants, which reaches human beings in the diet (Bierman and Rosen, 2005; Baligar, 1985; Barker and Pilbeam, 2007; Leigh et al., 1988). Potassium is the cation that most accumulates in the cell sap of sugarcane. Potassium function in sugarcane has been extensively reviewed elsewhere (Ng Kee Kwong, 2002). Plants require three factors for growth and reproduction: light, water, and nutrients. The third of these factors is where some of the major differences among farming systems occur. These differences frequently are described as biological and chemical methods of maintaining soil fertility. It is important to understand both biological and chemical processes to effectively and efficiently provide plants with nutrients. All essential nutrients are equally important for healthy plant growth, but there are large differences in the amounts required. N, P, and K are considered primary macronutrients due to their importance in the process of plant development (Bierman and Rosen, 2005). In particular, potassium in the soil originates from the decomposition of minerals. This nutrient is absorbed by plants mainly during the vegetative growth stage (Baligar, 1985). The absorption of nutrients such as potassium by plants from soil varies widely for different types of soil, vegetation, environmental conditions, and is a function of time. Management practices such as plowing, fertilization and irrigation can also influence this absorption (UNSCEAR, 2000; Paschoa et al., 1984; Alam et al., 1997). In addition, there may be variations in the concentration of radionuclides in different parts of the plant (Paschoa et al., 1984). Potassium is one of the most abundant minerals present in the lithosphere. Soil concentrations of this mineral vary widely. In accordance with its availability to plants, soil potassium is ascribed to

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four different pools: soil solution, exchangeable K, fixed K, and lattice K. As plants can only acquire K^+ from solution, its availability is dependent upon the nutrient dynamics as well as on total K content. The release of exchangeable K is often slower than the rate of K^+ acquisition by plants and, consequently, K^+ content in some soils is very low (Vieira, 1983). Potassium is the most important nutrient in sugarcane development and acts as an enzyme activator in the plant metabolism such as in photosynthesis, protein synthesis and translocation of sucrose from leaves to the stalk storage tissues. The study of potassium in sugarcane increased after verification of its correlation with the sucrose content in the plant. Sugarcane has an increased need to metabolize glucose in the first months of growth (Alam et al., 1997). In the human body, potassium concentration is around 5% of the minerals present in our body, is essential to maintain fluid balance and, together with calcium, it helps in controlling the activity of nerves and muscles (UNSCEAR, 2000).

Many works about potassium distribution in sugarcane have been developed in the recent decades indicating the great importance of this theme in different research areas (Silveira et al., 2009b; Vieira, 1983; Rehm and Schmitt, 1997; Ashley et al., 2006; Cesnik and Miocque, 2004; Perez and Melgar, 2000; Zeng et al., 1999). Sugarcane is a tall perennial grass of the genus *Saccharum* and, one of the most important field crops in the tropics, since it is cultivated in around a hundred countries. Nowadays, there is a great interest in the use of sugarcane as biomass, i.e., a renewable energy source (Cesnik and Miocque, 2004). Sugarcane cultivation is one of the most important agricultural activities in Brazil and very important for the Brazilian economy. It is used to produce sugar, liquor and biofuel. This biofuel is considered low-polluting, and is used to generate energy in industries and to move many transportation vehicles in Brazil since 1975.

Some authors studied the distribution of potassium in sugarcane grown by checking the absorption rate from a soil prepared with chemical fertilizers, e.g. phosphate fertilizers NPK (Ng Kee Kwong, 2002; Zeng et al., 1999). Since K is very relevant in sugarcane growth, development, yield and quality, knowledge of the potassium distribution is of great importance for many research areas. In this work, we have studied the dynamic potassium distribution in each part of the sugarcane using gamma ray spectrometry (UNSCEAR, 2000; Barker and Pilbeam, 2007). The investigation of potassium in sugarcane was carried out during plant growth. A periodic study of the potassium concentration in soil and also in different parts of the plants from roots to stalk and leaves was performed. The concentrations of potassium in root, stem and leaves were measured every two to three months about five months after planting the sugarcane. This study lasted for 18 months from the soil preparation, cultivation and periodic crops. We have used only a natural fertilizer made with the sugarcane bagasse which was prepared only at planting. To describe the evolution of the potassium distribution in sugarcane we proposed a phenomenological model assuming that the potassium incorporation rate is proportional to the difference between the element concentration in the plant and a very long term equilibrium value and it is coupled to a resource-limited growth model.

2. Experimental procedure

Dozens of sugarcane seedlings were planted in an area of 50 m^2 at the Centro Universitário da FEI, in the city of São Bernardo do Campo, Brazil. The seedlings were donated by Usina de Boicana. A compost, made from sugarcane residuous, was added to the soil. The first harvest of samples to be analyzed was made two months after the initial planting. The harvest of sugarcane samples was repeated several times. After the harvest, the sugarcane is separated in root, stem and leaves. They were crushed, dried at 100 °C, and then ground and sealed off in cylindrical polyethylene containers of 200 m^3. The activity concentration of ^{40}K was measured with gamma spectrometry. The ^{40}K radioisotope represents 0.0117% of natural potassium and the nucleus ^{40}K decays by electron capture with 10.72% to the nucleus ^{40}Ar, emitting a gamma-ray of 1460 keV (UNSCEAR, 2000; Marczenko, 1976). The half life of the ^{40}K decay is of the order of 10^9 years. Therefore, the quantity of the isotope ^{39}K, which is the most abundant in nature, can be estimated from the measurement of the ^{40}K. To detect the emitted gamma rays, we used a simple measurement system available at Centro Universitário da FEI, consisting of a $3 \times 3-in^2$ NaI(Tl) scintillation detector placed inside a 7.0 cm – thick lead shield and a spectrometer unit (Canberra, USA) (Canberra, 2012). The data from each sample were acquired for a period of 8 h and the gamma-ray spectra were analyzed using GENIE-2000 software. A background gamma radiation spectrum was acquired in the same data acquisition time to be subtracted from the sample gamma radiation spectrum. This is the only gamma-ray contamination source which could influence our final results. A ^{60}Co standard source was used to calibrate the energy of the gamma-ray spectra. We performed six harvests of sugarcane. The activity calibration was performed using the IAEA quality assurance reference material: RGK-1, prepared in the same geometry of the samples.

Table 1
Potassium concentration, in g/kg, in each part of the plant as a function of the time, in days.

Time (days)	Root (g/kg)	Leaves (g/kg)	Stem (g/kg)	Soil (g/kg)
0	–	–	–	–
154	17.3 (15)	43.4 (28)	39.3 (22)	9.9 (6)
253	9.4 (16)	17.1 (23)	20.0 (23)	8.5 (6)
311	17.0 (18)	21.0 (18)	24.0 (22)	–
373	9.6 (14)	16.4 (13)	8.9 (12)	–
444	14.4 (27)	19.5 (44)	18.6 (24)	9.5 (7)
519	11.8 (15)	17.8 (29)	12.9 (17)	–

3. Experimental results

Table 1 shows the potassium concentration, in g/kg, in each part of the plant as a function of the time in days. These results were obtained from the measurement of ^{40}K concentration. An alternative view is presented in Fig. 1. According to the results, the values

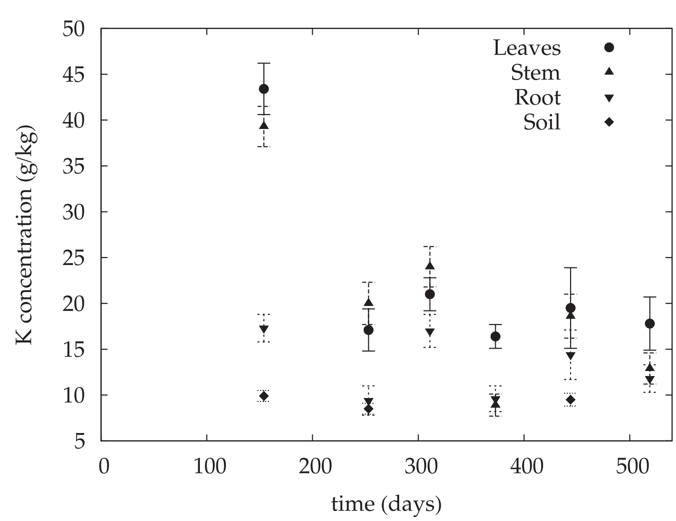

Fig. 1. Potassium concentration in sugarcane stem, leaves and roots as a function of time in days.