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Influence of soil types and osmotic pressure on growth and ^{137}Cs accumulation in blackgram (*Vigna mungo* L.)

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ABSTRACT

A pot experiment was conducted to study the effects of soil types and osmotic levels on growth and ^{137}Cs accumulation in two blackgram varieties differing in salinity tolerance grown in Fukushima contaminated soils. The contamination levels of the sandy clay loam and clay soil were 1084 and 2046 Bq kg^{-1} DW, respectively. The ^{137}Cs activity was higher in both plants grown on the sandy clay loam than on the clay soil regardless of soil ^{137}Cs activity concentration. No significant differences were observed in all measured growth parameters between the two varieties under optimal water conditions for both types of soil. However, the growth, leaf water contents and ^{137}Cs activity concentrations in both plants were lower in both soil types when there was water stress induced by addition of polyethylene glycol. Water stress-induced reduction in total leaf area and total biomass, in addition to leaf relative water content, were higher in salt sensitive 'Mut Pe Khaing To' than in salt tolerant 'U-Taung-2' plants for both soil types. Varietal difference in decreased ^{137}Cs uptake under water stress was statically significant in the sandy clay loam soil, however, it was not in the clay soil. The transfer of ^{137}Cs from soil to plants (i.e., root, stem and leaf) was higher for the sandy clay loam for both plants when compared with those of the clay soil. The decreased activity of ^{137}Cs in the above ground samples (leaf and stem) in both plants in response to osmotic stress suggested that plant available ^{137}Cs decreased when soil water is limited by osmotic stress.

1. Introduction

The Fukushima Daiichi nuclear power plant (FDNPP) accident released radioactive materials that contaminated farmlands in Fukushima and its neighboring prefectures, affecting soil and agricultural products. A long-term problem is soil contamination by radioactive cesium, particularly by ^{137}Cs with a half-life of 30 years. The bioavailability of the soil ^{137}Cs affects its distribution in plants (Fesenko et al., 2001). In the long term, radiocaesium enters the human food chain primarily via root uptake from contaminated soil, either directly through the consumption of plant material or indirectly through the consumption of products from animals which have ingested contaminated plant matter. Consumer confidence in the food supply has suffered due to fears associated with radionuclides. Therefore, in order to utilize Fukushima land for the safe production of agricultural products, research efforts must be directed towards the growing of crops that do not accumulate radioisotopes in their edible portions as a means of overcoming some of the current environmental problems in these areas (Ohmori et al., 2014; Fujimura et al., 2015; Win et al., 2016a).

Generally, plant uptake of radiocaesium in soil is controlled by many factors associated with chemical and physical characteristics of soil, including pH, exchangeable potassium (K), magnesium, calcium, and sodium ions, cation exchange capacity (CEC), total carbon content (TC), total nitrogen content (TN), percentage of organic matter (OM%), clay content of the soil, climatic conditions, and plant genotype (Absalom et al., 1999; Zhu and Smolders, 2000; IAEA, 2006). The ^{137}Cs is known to be taken up from the soil by roots and transported to above-ground plant parts, such as leaves and seeds, which serve as food and feed (Sreenivasa et al., 2012). The level of root absorption is greatly affected by the behavior of the ^{137}Cs in the soil and the soil-to-plant transfer factor (TF) depends on the specific soil type and plant species (Absalom et al., 2001; Konoplev et al., 2002; Sachdev et al., 2006).

Within the soil, clay minerals are known to be the dominant adsorbents of ^{137}Cs (Cornell, 1993). In particular, the frayed edge sites of illite and vermiculite can fix ^{137}Cs strongly (Brouwer et al.,

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1983). Literature values suggest that the clay content of the soil is a dominant factor in diminishing the ^{137}Cs uptake, while soil organic matter increases plant uptake of ^{137}Cs (Kuhn et al., 1984; Evans and Dekker, 1966; Fredriksson and Eriksson, 1996). However, in the long term, the amount of ^{137}Cs in agricultural products depends not only on the soil type, but also on the density of contamination, the soil moisture regime, the agrochemical properties and, finally the plant genotypes (Arapis, 2011). Globally, soil moisture depletion, both singly and in combination with other environmental factors, also strongly affects plant growth and survival. The soil water content plays a major role in influencing ion uptake availability, for instance, because it strongly affects the diffusion and mass flow of ions towards the roots. Under drought conditions, the root cells may also shrink, reducing their contact with the soil (Carminati et al., 2009) and further inhibiting uptake due to a decline of hydraulic continuity and conductance (Cuneo et al., 2016). Therefore, soil moisture depletion can be expected to play an important role in ^{137}Cs transport systems and the method by which ^{137}Cs moves within cells.

Plant uptake and distribution of radionuclides have been investigated using different water regimes (Greger, 2006). It is supported that increased soil moisture content enhances radiocaesium mobility and availability in soils and consequently radiocaesium uptake by plants (Shalhevet, 1973; Arapis et al., 1997; Sanford et al., 1998). However, opposite findings have been reported that soil moisture stress enhanced ^{137}Cs uptake in plant and suggested that it might be due to an increased ^{137}Cs availability from dry soils (Ehlken and Kirchner, 1996; Prister et al., 2003; Goncharova, 2006). No consensus has been reached regarding these contradictory findings. The objective of this study was to study the growth and ^{137}Cs accumulation in two blackgram varieties as influenced by water stress in two contaminated agricultural soils that differ in their physiochemical properties.

2. Materials and methods

2.1. Soil sample collection and analysis

Soil samples differing in chemical and physical properties were collected from two different locations namely Miyanoiri and Nakasato in Nihonmatsu, Fukushima, where radioactive materials originating from the FDNPP caused contamination of agricultural land. Nihonmatsu is located approximately 50–60 km northwest of Tokyo Electric Power Company, FDNPP in Japan. The top layer (0–15 cm) of two farmers' fields were sampled, the samples were drawn at the corners of equilateral triangles at a distance of 10 m from each other and were mixed together to give a composite sample. The major soils types in these areas represent predominantly gray lowland soil and andosol soil, respectively. The soil samples were air-dried, ground with wooden hammer and screened to pass through a 2.0 mm sieve. The physico-chemical properties of the soils were determined according to conventional methods (Page, 1992) and the results were presented in Table 1.

Prior to plant growth, soil samples from each pot were collected, dried, ground using a mortar and pestle (100 mesh size), and homogenized for measurement of ^{137}Cs using a Ge detector (Seiko EG &G). All measurements were performed in triplicate in December 2012. Above samples of sieved soil (100 g) was determined the concentrations of ^{137}Cs and fractions of water and ion exchangeable ^{137}Cs. Water and ion exchangeable ^{137}Cs were determined according to Forsberg and Strandmark (2001). Samples were agitated for 24 h at room temperature, and ^{137}Cs concentrations in the solution were measured with a Ge semiconductor detectors.

2.2. Plant materials and growth conditions

Two blackgram (*Vigna mungo*) varieties, salt-tolerant 'U-Taung-2' and salt-sensitive 'Mut Pe Khaing To', were used (Win et al., 2016b). Seeds were surface sterilized by soaking in 70% ethanol for 5 min and then in 2.5% sodium hypochlorite solution for 30 s. Once drained, the seeds were rinsed 5 times with sterile distilled water. Then, seeds were planted in 3L plastic pots (20 cm diameter) containing 3 kg of the sample soil. For optimum growing of blackgram, experimental pots were placed in an artificial climate chamber at 30 °C/25 °C; day/night, 12 h light, 60% RH, and photosynthetic active radiation (PAR) of 500 mmol photons $m^{-2}s^{-1}$ at Tokyo University of Agriculture and Technology, Tokyo, Japan. After 7 days of growth, plants were thinned to three uniform plants per pot. Each pot was watered once per alternate day with full-strength Hoagland solution. The amount of solution added on each occasion was 500 mL per pot, and was always introduced in the form of a soft pour from the edge of the pot in order to avoid contamination of plant parts. The nutrient solution comprised 4.0 mM Ca $(NO_3)_2$, 4.0 mM KNO_3, 1.0 mM $MgSO_4$, 1.0 mM $NH_4H_2PO_4$, 1.0 mM $(NH_4)_2HPO_4$, 1 mMNaCl, 41.2 μM FeNaEDTA, 12.5 μM H_3BO_3, 0.39 μM $CuSO_4$, 1.59 μM $MnSO_4$, 1.0 μM $ZnCl_2$, and 0.5 μM $NaMoO_4$. The pH of the nutrient solution was adjusted to 6.0 with 0.1 mM KOH during the entire growing period.

2.3. Soil moisture regimes

At the first true leaf stage (15 days old), plants were irrigated once as described above with full-strength Hoagland solution containing 0% (control) or 20% polyethylene glycol 6000 (water stress) to adjust the soil moisture regimes to approximately −0.34 Mpa (field capacity, control) or −2.95 Mpa (water stress) osmotic potential of soil and grown for 10 days. The osmotic potentials of the PEG solution for each replication were evaluated using a vapour pressure osmometer (Wescor 5500). Treatments were performed according to irrigation practices and schedules. Measurements were then conducted at the end of water stress treatment.

2.4. Leaf relative water content and leaf area

Leaf relative water content (RWC) was determined during 8:30–10:00 at 10 day after treatment. For this purpose, the third trifoliate leaves from the top were used to determine the RWC by sampling 12 discs 7 mm in diameter. Leaf discs (7 mm in diameter) were excised by a loose-leaf punch and placed immediately into each sample bags of a cooler-box. The fresh weight (FW) of the discs was immediately recorded. Discs were then placed in closed Petri dishes with distilled water and incubated for 24 h under darkness at 4 °C. Samples were then removed from the water, lightly patted dry using Kimwipes, and immediately weighed to obtain the fully turgid weight (TW). The dry weight (DW) was obtained after oven drying for 48 h at 70 °C. The RWC was determined using the following equation (Filella et al., 1998):

$$RWC(\%) = \frac{\text{Fresh weight (FW)} - \text{Dry weight (DW)}}{\text{fully turgid weight (TW)} - \text{Dry weight (DW)}} \times 100$$

After the leaf area was measured with a leaf area meter (AAM-8; Hayashi Denko Co., Tokyo, Japan), leaves, shoots, and roots were oven-dried at 80 °C for 48 h and dry weight was determined.

2.5. ^{137}Cs activity concentration and transfer factor (TF)

Oven-dried roots, stems and leaves were crushed into a powder