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Agricultural use of Samarco's spilled mud assessed by rice cultivation: A promising residue use?

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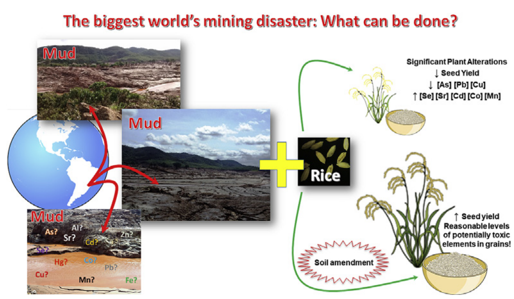
HIGHLIGHTS

- Low content of toxic elements in rice grains cultivated with mud.
- Soil containing mud-50% intensely damaged the plants.
- Simple soil amendment helped on rice growth in the mud.
- Possible use of the mud for agricultural practices.

GRAPHICAL ABSTRACT



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ABSTRACT

Mining activity is one of the main responsible for accumulation of potentially toxic elements in the environment. These contaminants are absorbed by plants served as food that could be a risk to human health, such rice. Rice is a staple food with known accumulation of toxic elements. The recent collapse of a mining dam operated by Samarco Mining Company spilled around 50 million m^3 of Fe-mining waste in the environment, including rivers and farming areas. In the present study, concentrations of As, Cd, Hg, Pb, Co, Zn, Mn, Cu, Fe, Al, Se, and Sr were determined in soils, roots and grains of rice plants cultivated in soil containing Samarco's residual mud (0, 16, 34 and 50%). Further, rice plant agronomic parameters (chlorophyll, carotenoids, grain yield, mass, height) were assessed. Rice cultivated at Samarco's residual mud produced grains with low levels of As, Cd and Pb. However, the excess of mud (50%) during the rice cultivation reduced roots' growth and grains yield. Chlorophyll (*a* and *b*) and carotenoids contents were significantly lower in all mud cultivations, mainly mud-50%. Our findings suggest that plant alterations induced by the mud were associated to the deficiency of nutrients and the physical properties of the mud. Soil fertilization by organic matter and top soil provided conditions for plant development.

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Soil amendment
Agronomic parameters

Therefore, considering the experimental conditions here used, we showed that is possible the use of the affected land for agriculture and reforestation after soil amendment.

1. Introduction

On November 5, 2015, the biggest socio-environmental disaster involving iron mining occurred in Brazil. The Fundão dam, operated by Samarco, a mining company located at the town of Mariana (State of Minas Gerais), collapsed, spilling 50 million m^3 of residual-mud over Bento Rodrigues sub-district. This accident caused the partial destruction of this district and uncountable socioeconomic and environmental damages to the entire river basin (Santarém, Gualaxo do Norte, Do Carmo and Doce rivers). The disaster left 17 dead, more than 600 homeless people and interrupted the water supply services in 35 cities in the state of Minas Gerais and 3 cities in the state of Espírito Santo (SEDRU, 2016). Moreover, the mud spilled by Samarco's dam traveled over 600 km of watercourse until reach the Atlantic Ocean and destroyed approximately 1.5 ha of farming lands (Dos Santos et al., 2006).

Mining is one of the main responsible for the accumulation of chemical elements in the environment. Dust, waste and disposal of contaminated water are generated during the mining activities. In addition, accidental disruption of tailings dams can easily contaminate the environment by pollutants dispersions, destabilizing soils and water supplies (rivers and aquifers) over long distances (Lei et al., 2010). Assuming that mud may have toxic elements, the soil contamination is an environmental concern once it could accumulate in crops, magnifying in the food chain, causing ecosystem unbalance and several human health problems (Dos Santos et al., 2006).

Considering the most studied chemical elements in toxicology (As, Cd, Hg and Pb), the effect of accumulation is more important mainly when cultivation of plant destined to human consumption (Dos Santos et al., 2006). In this context, rice, a cereal consumed by approximately 50% of the world population, presents known ability of accumulation for As, Cd, Pb and Hg (Argumedo-García et al., 2013; Liu et al., 2003; Norton et al., 2014; Rahman et al., 2008; Segura et al., 2016a; Yang et al., 2006). A previous study have shown that Cd concentrations in rice cultivated at areas close to mine sites were significantly higher than those from distant areas (Ok et al., 2011). Regarding As, it's well known that rice can accumulate As^{3+} and As^{5+}, the most toxic As-forms found in food, in the grains (Abedin et al., 2002; Ma et al., 2008; Raab et al., 2005). Mercury present in the paddy soils can be methylated by soil microorganisms and then accumulate in the grains as methyl-Hg, the most toxic form of Hg (Zhao et al., 2016). Furthermore, Norton et al. (2014) found elevated Pb-levels in rice grains collected from known contaminated/mine impacted regions in China.

With this background, the present study aimed to evaluate the use of mud for cultivation, using as model rice, an important plant used for human diet with ability for accumulation of toxic elements. For this purpose, we grown rice in soils containing increased levels of the spilled mud for evaluation of the accumulation of chemical elements and agronomic characteristics of the plants.

2. Materials and methods

2.1. Reagents and materials

High purity water (resistivity 18.2 MΩ cm) was used throughout the experiments (Master All Gehaka, Brazil). Nitric acid (HNO_3, 65%, Synth Brazil) was previously sub-distilled (DST-100 Savillex, USA). All plastic bottles and glassware have been washed with Extran® and acid bath (15% v/v HNO_3) during 24 h. After that, all materials have been rinsed 5 times with ultra-pure water and then, it was dried in a class 100 laminar flow hood (Filterflux, Brazil). Solutions and standards were stored in cleaned plastic bottles. The materials used for *in vitro* culture were autoclaved and the experiments were conducted in a class 100 laminar flow hood (Filterflux, São Paulo, Brazil). A microwave oven Ethos Easy (Milestone, Italy) was used for sample digestion. An inductively coupled plasma mass spectrometer (ICP-MS Agilent 7900, Hachioji, Japan) was used for determination of all analytes.

2.2. Mud sampling and rice cultivar

Samarco's mud was collected on November 28th, 2015 at the margin of Santarém River, at Bento Rodrigues (Mariana, State of Minas Gerais, Brazil). The mud was collected in plastic bags at the coordinates S/W 20°14′11.37"/43°25′20.02″, altitude of 2312 m, south of Bento Rodrigues. Detailed information with regard to mud sampling is presented elsewhere (Segura et al., 2016b). Rice (*Oryza sativa* L.) cultivar BR IRGA 409, from the Rice Institute of Rio Grande do Sul (Brazil), was using during whole experiments due to its high yielding and widely cultivation in Brazil.

2.3. In vitro culture

Previously, rice seedlings were *in vitro* cultivated for screening of the possible effects associated to the mud. Firstly, the seed husks were removed. Seeds were washed in 20 mL of distilled water containing 50 μL of Tween 20 during 1 min, incubated with 70% ethanol for 1min, sterilized in 2.5% NaClO for 20 min and then washed 5 times with sterile distilled water. Seeds were soaked for 2 days at room temperature for pre-germination. Then, the germinated seeds were sown in 15 ml sterile-glass tubes using poor (water, w) or rich (Murashige & Skoog, MS) growth medium, as follows:

Water (w) control group, N = 5: agar;
Group 3.0 g Soil − w (N = 5): top soil + agar;
Group 3.0 g Mud − w (N = 5): mud + agar;
Group 7.5 g Soil − w (N = 5): top soil + agar;
Group 7.5 g Mud − w (N = 5): mud + agar;
Murashige & Skoog (MS) control group, N = 5: MS + agar;
Group 3.0 g Soil − MS (N = 5): MS + top soil + agar;
Group 3.0 g Mud − MS (N = 5): MS + mud + agar;
Group 7.5 g Soil − MS (N = 5): MS + top soil + agar;
Group 7.5 g Mud − MS (N = 5): MS + mud + agar.

Mud or top soil were weighed separately in each glass-tube and autoclaved prior to use. For water, agar or MS medium, 6 g/L of Phytagel (Sigma-Aldrich, USA) was used to increase the physical stability of the growth medium. When using MS basal salt mixture (4.3 g), the pH was adjusted to 5.7. Seedlings were grown for 15 days in a growth room at 27 ± 2 °C, 16 h:8 h (light: dark) photoperiod. Finally, shoots and roots length were measured. Further, we determined the photosynthetic pigments. The chlorophyll and carotenoid determinations were performed with 40 mg of leaf