Uso do sorgo biomassa para biorremediação de ambientes contaminados com metais pesados

Use of biomass sorghum for the bioremediation of heavy metal-contaminated environments

Uso de sorgo de biomasa para la biorremediación de ambientes contaminados con metales pesados

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Resumo

Áreas contaminadas com metais pesados são um problema recorrente em uma sociedade que demanda cada vez mais por combustíveis fósseis, defensivos agrícolas e fertilizantes. Métodos tradicionais de recuperação dessas áreas são geralmente muito onerosos e a fitorremediação pode ser uma solução para a descontaminação desses ambientes, por meio da remoção desses contaminantes do solo, por meio da colheita das plantas cultivadas no local afetado, em função da extração desses elementos do solo. A parte colhida pode ser utilizada para fins não alimentares, como, por exemplo, para a produção de energia. Nessa direção, a planta de sorgo surge como uma alternativa por apresentar uma boa capacidade de acúmulo de biomassa em um curto intervalo de tempo e pelo potencial de produção de bioeletricidade. O objetivo desse estudo foi avaliar o uso do sorgo biomassa para biorremediação de ambientes contaminados com os metais pesados Cu e Ni. O experimento foi conduzido no Município de Jaguariúna/SP, utilizando 4 doses de Ni (0, 10,5, 47 e 210 mg kg^{-1}) e de Cu (0, 200, 300 e 400 mg kg^{-1}). As plantas de sorgo apresentaram um bom desenvolvimento mesmo nas mais altas doses de Cu e Ni aplicadas no solo. Os maiores teores de Cu e Ni foram concentrados nas raízes. O sorgo biomassa pode ser indicado para fitorremediação de ambientes contaminadas com Cu e Ni.

Palavras-chave: Cobre; Fitorremediação; Níquel; *Sorghum bicolor*.

Abstract

Heavy metal-contaminated areas are a recurring problem in a society that increasingly demands fossil fuels, pesticides and fertilizers. Traditional methods to recover these areas are generally very expensive, and phytoremediation can be a solution for their decontamination by removing these contaminants from the soil through the harvest of the plants grown in the affected site, as these elements are extracted from the soil. The harvested part can be used for non-food purposes, such as energy production. In this scenario, the sorghum plant emerges as an alternative owing to its high ability to accumulate biomass in a short time and bioelectricity production potential. This study proposes to examine the use of biomass sorghum for the bioremediation of environments contaminated with the heavy metals Cu and Ni. The experiment was carried out in the municipality of Jaguariúna - SP, Brazil, using four doses of Ni (0, 10.5, 47 and 210 mg kg^{-1}) and Cu (0, 200, 300 and 400 mg kg^{-1}). The sorghum plants exhibited good development even at the highest Cu and Ni doses applied to the soil. The highest levels of Cu and Ni were concentrated in the roots. Biomass sorghum can be indicated for the phytoremediation of environments contaminated with Cu and Ni.

Keywords: Copper; Nickel; Phytoremediation; *Sorghum bicolor*.

Resumen

Las áreas contaminadas con metales pesados son un problema recurrente en una sociedad que demanda cada vez más combustibles fósiles, pesticidas y fertilizantes. Los métodos tradicionales de recuperación de estas áreas son generalmente muy caros y la fitorremediación puede ser una solución para la descontaminación de estos ambientes, eliminando estos contaminantes del suelo, cosechando las plantas que crecen en el sitio afectado, debido a la extracción de estos elementos del suelo. La parte cosechada se puede utilizar para fines no alimentarios, como la producción de energía. En este sentido, la planta de sorgo aparece como una alternativa porque tiene una buena capacidad para acumular biomasa en un corto período de tiempo y el potencial para producir bioelectricidad. El objetivo de este estudio fue evaluar el uso de la biomasa de sorgo para la biorremediación de ambientes contaminados con metales pesados Cu y Ni. El experimento se llevó a cabo en la ciudad de Jaguariúna / SP, utilizando 4 dosis de Ni (0, 10.5, 47 y 210 mg kg^{-1}) y Cu (0, 200, 300 y 400 mg kg^{-1}). Las plantas de sorgo mostraron un buen desarrollo incluso con las dosis más altas de Cu y Ni aplicadas al suelo. Los niveles más altos de Cu y Ni se concentraron en las raíces. La biomasa de sorgo puede estar indicada para la fitorremediación de ambientes contaminados con Cu y Ni.

Palabras clave: Cobre; Fitorremediación; Níquel; Sorgo bicolor.

1. Introduction

Statistical projections indicate that the global energy demand will be 57% higher by the year 2025, which will intensify the neglected exploitation of finite natural resources, consequently causing atmospheric pollution by the emission of greenhouse gases—carbon dioxide, mainly (NRC, 2012). In opposition to this scenario, research and development centers encourage the possibility of obtaining sustainable sources of energy from the processing of plant biomass from agricultural and forestry crops, especially sugar cane, elephant grass, eucalyptus, pine, maize, canola, beet and biomass sorghum (Korkas et al., 2016; Zale et al., 2016).

Likely originating in Africa, sorghum (*Sorghum* spp.), a C_4 plant species, is characterized by its hardiness to pest attack; wide physiographic adaptation to tropical, subtropical and temperate climatic conditions; tolerance to water deficiency; high photosynthetic capacity; and aptitude for agricultural mechanization. In particular, together with sugarcane (*Saccharum* spp.), the biomass sorghum crop assumes the position of promising raw material for the diversification, expansion and consolidation of the Brazilian energy matrix. This potential is thanks to its early biological cycle, of 150 to 180 days, which varies according to the sensitivity of the genotype to the photoperiodic stimulus; the possibility of cultivation in marginal areas unlikely to the establishment food crops; and, mainly, its high fresh matter yield, of 120 to 150 t ha^{-1}, as compared with the 20 to 35 t ha^{-1} of Brachiaria and guinea grasses and artificial forests of *Eucalyptus* spp. and *Pinus* spp. (May et al., 2013; May et al., 2015).

Another important characteristic of this crop is the possibility of using regrowth, since the root system of sorghum remains alive after the original plant is harvested, allowing regrowth. In addition, the sorghum crop stands out as promising for use in the phytoremediation of soils contaminated by heavy metals such as nickel, copper and other elements. These metals can be part of the mineral composition of the plant, or they can contaminate the soil and water through the use of fertilizers and pesticides, coal and oil combustion, vehicular emissions, mining, smelting and incineration of urban and industrial waste (Ernst, 2002).

Phytoremediation is a technique that has been used in projects for the bioremediation of heavy metal-contaminated environments. In this technique, bioindicator plants can be used by exploiting their physiological characteristics to remove, render inert or contain pollutants dispersed in the environment (Pio et al., 2013). The most studied form of phytoremediation is phytoextraction, whereby plants extract heavy metals (or other pollutants) and accumulate them in their tissues. These contaminants are removed from the medium through the harvest of the plants, which can be used later for non-food purposes, e.g., in the energy industry (Mirza et al., 2014). Plants that stand out in this process are called heavy-metal hyperaccumulators. These are able to concentrate high levels of metals in their biomass that would be toxic to other plant species able to grow under identical conditions (Romeiro et al., 2007).

Regardless of their origin, metals are accumulated in all plant tissues, thus being introduced into the food chain. Some metals (e.g. zinc, copper and nickel) are essential to the growth of vegetables, as they are part of the constitution of enzymes and proteins. However, at high concentrations, they can become toxic to plants (Han et al., 2005). In this way, regular intake can help to meet some essential needs. Several elements have applications as nutrients or act on human metabolism. Nonetheless, heavy metals may also be present, which are

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potentially toxic at varying concentrations depending on the part, species and physiological age of the plant, in addition to being absorbed differently in each plant (McDowell et al., 1993; Maiga et al., 2005).

In short, heavy metals are those whose relative density is higher than four and which are related to contamination and high toxicity. In recent years, the toxic effects of heavy metals on living organisms—mainly as a result of their continuous anthropogenic mobilization in the environment—have garnered considerable worldwide attention (Seebaugh et al., 2005; Schmitt-Jansen et al., 2008).

Scientific information on the use of biomass sorghum as an agent in the bioremediation process is still scarce. On this basis, the present study was developed to examine the use of biomass sorghum for the bioremediation of environments contaminated with the heavy metals copper and nickel.

2. Material and Methods

The study was conducted in a greenhouse in the experimental area of Embrapa Meio Ambiente, located in the municipality of Jaguariúna - SP, Brazil.

The research was a quantitative study, according to the characterization of Pereira et al. (2018) and it was developed using a randomized-block design with eight treatments, consisting of two heavy metals (copper and nickel) and four doses of each element: 0, 10.5, 47 and 210 mg kg^{-1} of Ni, using $NiSO_4$ as the source, and 0, 200, 300 and 400 mg kg^{-1} of Cu, using $CuSO_4$ as the source. Each treatment was tested in eight replicates. The doses of nickel and copper were determined based on the methodology of Zeitouni (2003).

The soil used was classified as dystrophic Red-Yellow Latosol of clayey texture (Santos et al., 2018), which was collected in the 0-20 cm layer, air-dried and passed through a 2-mm sieve to fill the pots. Pots containing 10 L of soil were used for each studied plant. The collected soil was limed to increase base saturation to 60%. The 8-28-16 planting fertilizer formulate was applied by incorporation at a depth of 5 cm from the soil surface, at the rate of 200 kg ha^{-1}. Topdressing was carried out when the plants reached the V3 vegetative stage (three definitive leaves), using the 20-00-20 formulate, at the proportional dose of 200 kg ha-1.

Irrigation was applied by an automated drip system that was programmed for daily irrigation according to the needs of the plants throughout the development cycle.

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The pots received the treatments with heavy metals 90 days before planting, soon after the soil liming operation, which was characterized as the pot incubation phase. Sowing was carried out on August 16, 2017. To apply the treatments, the salts were mixed with the total soil volume of each pot, using a concrete mixer, at the respective studied doses, for each evaluated metal. During the pot incubation period, the soil moisture was maintained at field capacity. The preparation of the vessels followed the methodology of Zeitouni (2003).

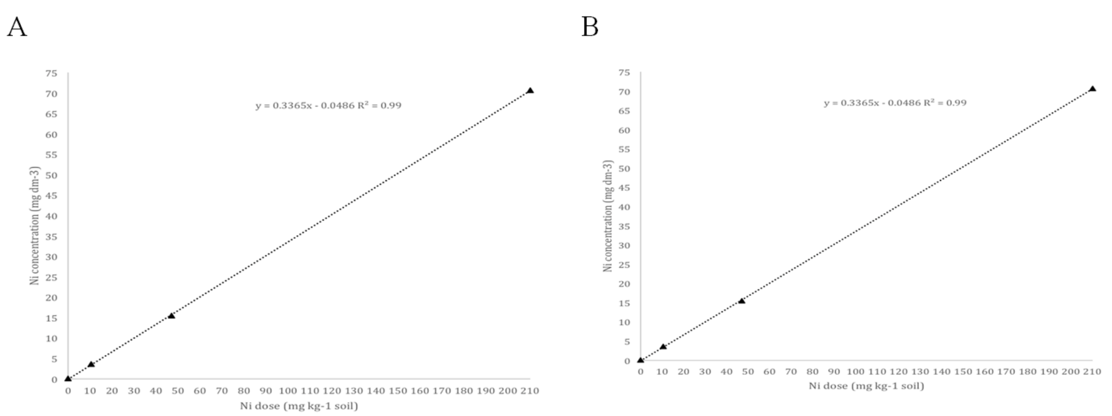
The sorghum cultivar used was CMSXS 7012, which belongs to the breeding program of Embrapa Maize and Sorghum.

At the end of the 150-day experimental cycle, the plants were evaluated for height, number of leaves, leaf fresh mass, stem fresh mass and root dry mass, in eight replicates per treatment. The plant parts (leaf, stem and root) were also analyzed for the copper and nickel concentrations in the respective dry masses of each treatment. In addition, the copper and nickel contents in soils were analyzed according to the applied treatments. Chemical analyses of the collected plants and soils were carried out at the Soil Fertility Laboratory of the Embrapa Meio Ambiente unit in Jaguariuna - SP, Brazil, considering only the first three replicates per treatment, through nitric-peroxide digestion, in a NIST-certified reference standard.

3. Results and Discussion

According to soil analysis, which was carried out immediately after the pot incubation period, the application of increasing Cu and Ni doses led to an increase in their total contents in the soil, indicating that the heavy metals were retained in it (Figure 1).

Figure 1. Copper (A) and nickel (B) concentrations in the soil, according to the applied dose of the element.



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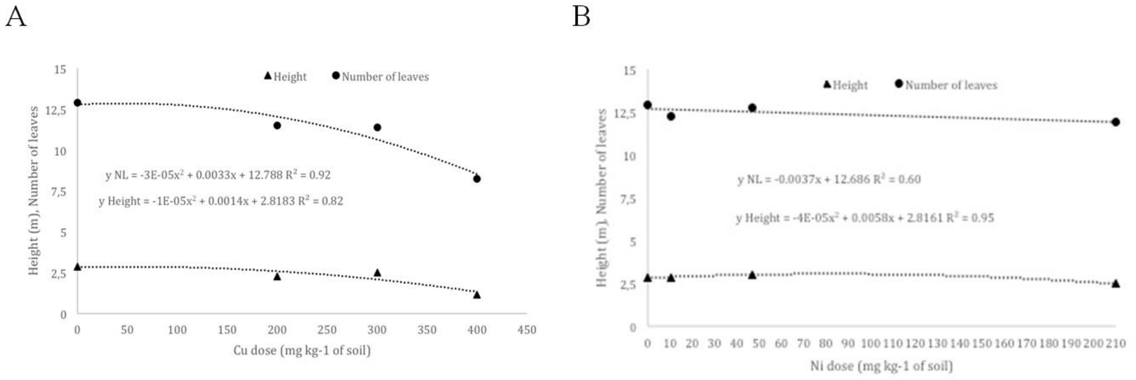
It appears that the elements Ni and Cu responded positively in the soil to the increase in the applied doses of these elements. These increases were linear for Ni and quadratic for Cu, as a function of the doses of the respective elements.

The behavior of plant height and number of plant leaves produced at different doses of Ni and Cu can be seen in Figure 2.

Figure 2. Height and number of leaves of biomass sorghum plants according to the copper (A) and nickel (B) dose applied to the soil.



Source: The authors.

The application of increasing Cu and Ni doses to the soil elicited a decrease in plant height and number of leaves (Figure 2), with a more pronounced effect seen on copper than nickel. Copper is an essential micronutrient for plants. Nevertheless, because it is a heavy metal, high concentrations of this element in the soil solution can be toxic to microorganisms, plants, animals and humans (King, 1996). This explains the reduction in the number of leaves and height of the sorghum plants with the increasing copper concentration in the studied treatments.

Despite the reduced development of the sorghum plants, it remains a good option when compared with other crops that are highly sensitive to copper, since the plants in the studied treatments did not show signs of toxicity. A typical visual symptom of heavy-metal toxicity is internerval chlorosis of the leaves, which evolves to necrosis of the borders and tips, or even total necrosis. Accioly et al. (2004) found that eucalyptus species under excess heavy-metal levels presented symptoms similar to those described above. With regard to nickel extraction, sorghum is a highly viable alternative, considering that the metal caused the death of all common-bean plants at the dose of 210 mg kg^{-1} in an experiment led by Berton et al. (2006).

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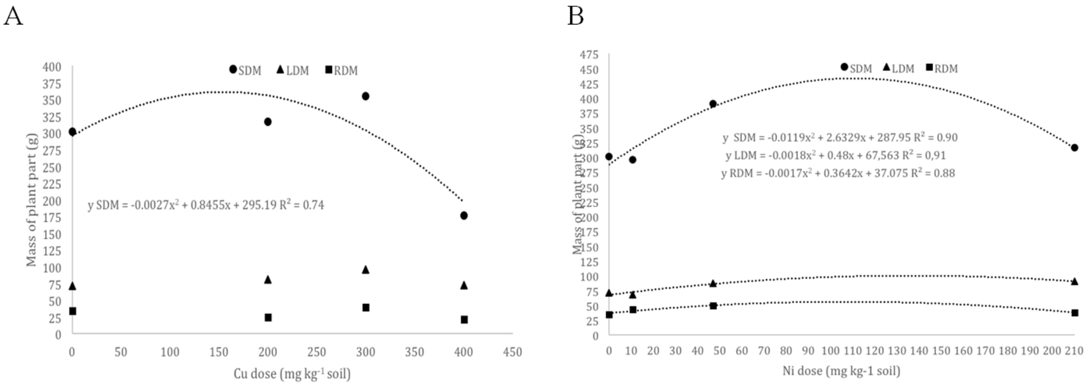
In Figure 3, the accumulation of fresh mass from the stalk of the sorghum plants was analyzed in the doses of Ni and Cu studied.

Figure 3. Stem fresh mass (SFM), leaf fresh mass (LFM) and root dry mass of biomass sorghum plants, according to the copper (A) and nickel (B) dose applied to the soil.



Source: The authors.

Stem fresh mass accumulation showed an upward trend up to the Cu dose of 110 mg kg^{-1} and the Ni dose of 156 mg kg^{-1}. At higher doses of these metals, there was a reduction in biomass accumulation. Excess copper can reduce photosynthetic rate, consequently reducing the production of photoassimilates by the plant, which implies a decrease in plant growth (Kabata-Pendias, 2011). In a study carried out by Revoredo & Melo (2006), the dry mass production of leaves and stems was affected by the nickel dose, with the treatment that received 746 mg kg^{-1} of Ni via sewage sludge producing more leaf dry mass than the other evaluated treatments, whereas control treatment showed the highest stem dry mass. According to Andreazza & Camargo (2011) castor plants (*Ricinus communis* L.) exhibited high biomass production in soils contaminated with copper.

The levels of copper and nickel in the dry mass of leaves, stems and roots of sorghum plants according to the dose of copper and nickel applied to the soil are shown in Figure 4-A and 4-B.

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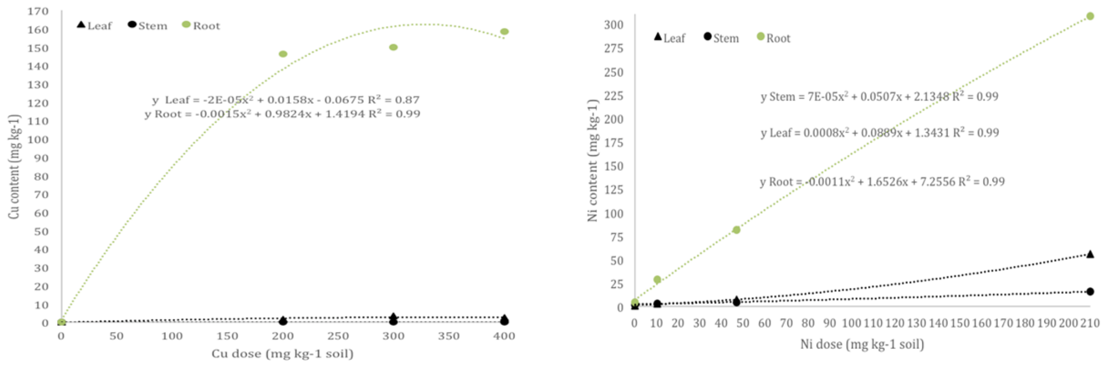
Figure 4. Copper content in the dry mass of different parts of biomass sorghum plant (leaf, stem and root), according to the copper (A) and nickel (B) dose applied to the soil.

A B



Source: The authors.

The largest amounts of Cu are found in the root, then in the leaf and, lastly, in the stem of the sorghum plants. The concentrations in the different plant parts followed the total contents present in that plant. The highest Ni contents were also found in the roots. At the highest Ni dose in the soil, there was an increase in the accumulation of the metal in the leaves.

Most of the Cu present in the roots can be attributed to the mechanism of reduction of cation diffusion in the internal part of the tissue, which protects the aerial part from intoxication. Another possible reason is low the mobility of copper in the soil-plant environment (Marsola et al., 2005). Higher levels of Cu and Ni in the root system of sorghum plants are common in several heavy-metal-tolerant species due to the ability of this organ to reduce metal ions available in the soil (Römheld, 1991). Alternatively, they may be related to the association of the microbiota with the rhizosphere, which reduces the mobilization of heavy metals to higher vegetative parts such as leaves and stems, thus providing tolerance to high concentrations of these metals (Rouch et al. 1995; Pulsawat et al., 2003).

Heavy-metal accumulation in the roots was also observed in a study by Mokhtar et al. (2011), in which the copper removal percentages for *Eichhornia crassipes* and *Centella asiatica* were 97.3 and 99.6%, respectively. In the experiment led by Revoredo & Melo (2006), the accumulated Ni content in sorghum plants was also higher in the roots than in the leaves, stem and grains.

Thus, according to the results found, the sorghum plants absorbed part of the heavy metals added to the soil, being affected in their growth by them, and presenting the roots with a greater accumulation of Ni and Cu.

4. Conclusions

The biomass sorghum plant exhibited tolerance in soil with excess Cu and Ni. This plant species can be indicated for the phytoremediation of areas contaminated with these heavy metals, as it has good extraction capacity and tolerance to these metals, in addition to providing high biomass production in a short period of development when compared with other crops.

To improve the results found, new studies can be used with other sorghum cultivars, and also perform other types of chemical analysis of metals.

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