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Phytoremediation: a viable technique in sugarcane farm heavy metals contaminated

Fitorremediação: uma técnica viável em canaviais contamindos com metais pesados

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ABSTRACT

Heavy metals (HMs) affect more than 500 million hectares worldwide. These elements lead to a decrease in world plant production and provoke deleterious effects on human health. Phytoremediation is a technique that conserves and remediates soil contaminated by these pollutants. The literature indicates that phytoremediation is operationally simple and economically viable, however, there is scarce literature on this subject in Brazil. In this way, we assess a simulated case study to crop plants sugarcane (*Saccharum officinarum* L.) in an agricultural area contaminated by HMs. We found that the economic deficit caused by phytoremediation in the context addressed was US$ 53,644.29, a value higher than the annual profit from sugarcane production, however, in this hypothetical scenario, the financial payback period would be achieved seven years after phytoremediation implementation. We conclude that phytoremediation is an economically viable technique and has easy applicability for soil decontamination and conservation polluted with HMs in brazilian farmland.

Keywords: farmland, hypothetical scenario, inorganic pollutants, phytoremediation cost, soil decontamination.

RESUMO

Os metais pesados (MTs) afetam mais de 500 milhões de hectares em todo o mundo. Esses elementos levam à diminuição da produção vegetal e provocam efeitos deletérios à saúde humana. A fitorremediação é uma técnica que conserva e remedia solos contaminados por esses poluentes. A literatura indica que a fitorremediação é operacionalmente simples e economicamente viável, porém, há escassa literatura sobre este assunto no Brasil. Desta forma, avaliou-se um estudo de caso simulado para o cultivo de plantas de cana-de-açúcar (*Saccharum officinarum* L.) em área agrícola contaminada por MTs. Constatamos que o déficit econômico acarretado pela fitorremediação no contexto abordado foi de US$ 53.644,29, valor superior ao lucro anual de produção de cana-de-açúcar, porém, neste cenário hipotético, o período de retorno financeiro seria alcançado sete anos após a implantação da fitorremediação. Concluímos que a fitorremediação é uma técnica economicamente viável e de fácil aplicabilidade para descontaminação e conservação de solos poluídos com MTs em terras agrícolas brasileiras.

Palavras-chave: áreas agrícolas, cenário hipotético, custo da fitorremediação, descontaminação de solos, poluentes inorgânicos.

INTRODUCTION

Heavy metals (HMs) are chemical elements that have electrical and thermal conductivity, hardness, ductility, and malleability similar to each other (Duffus, 2002), such as arsenic (As), cadmium (Cd), lead (Pb), and chromium (Cr). Besides, are naturally present in sediments, water bodies, and soils as a consequence of their source material and volcanic eruptions (Ali et al., 2019). However, HMs soil availability increased in recent years due to irregular waste disposals, such as industrial effluents, mineral extraction, and agricultural activities. Among agricultural activities are listed pesticides, herbicides, biosolids, fertilizers derived from phosphate rocks, and irrigation with contaminated water (Haroon et al., 2019; Ali et al., 2019).

In the last decade, the literature reported that HMs affect a significant portion of soils around the world. In 2015, HMs covered 250 million hectares (ha), representing 13.7% of farmlands and in 2018, 500 million ha were diagnosed as contaminated (Mani et al., 2015; Liu et al., 2018). The People's Republic of China is the country with the most contaminated areas registered in the world, with 80 million contaminated ha (He et al., 2015). According to Odoh et al. (2019), the presence of these inorganic contaminants in African soil causes socioeconomic and health problems. These occur because soil contamination reduces productivity, reducing family income, and, in addition, the food produced in these areas if ingested for long periods causes health disorders.

Furthermore, HMs soil pollution is estimated to impact the world economy by US$10 billion per year (He et al. 2015). In the São Paulo state (Brazil) about 1,273 sites contaminated by HMs are registered (Companhia de Tecnologia de Saneamento Ambiental do Estado de São Paulo, 2020). In this way, the use of sustainable techniques that remediate and conserve soils from these contaminants is extremely important (Ashraf et al., 2019). In Brazil, according to Bernardino et al. (2016), there is great potential for the use of phytoremediation, due to its flora and climate, which can enhance the accumulation or stabilization of pollutants by plants.

Phytoremediation is an environmental decontamination technique characterized by the use of plant species to minimize the toxic effects, such as HMs on water, soil, and air. Furthermore, it is considered a "clean" technique, as it uses solar energy as the main source of energy, improves the "health" of the soil, promoting porosity, and consequently, increasing water infiltration and erosion management (Rostami and Azhdarpoor, 2019; Ramborger et al., 2021; Tavares, 2009). This technique is considered very efficient, adaptable to the environment, socially accepted, ecologically viable, and aesthetically pleasing (Nedjimi, 2021; Shah and Daverey, 2020; Yan et al., 2020).

Several studies report that plant species to perform phytoremediation must have specific characteristics, for example, robust root system, hyperaccumulate multiple heavy metals, and heavy metals stress tolerance (Haider et al., 2021; Chen et al., 2020; Prabakaran et al., 2019). Besides, species belonging to the botanical genus *Brassica* are indicated to perform the HM phytoremediation, such as turnip (*Brassica rapa* L.) (Navarro-León et al., 2019; Rizwan et al., 2018), canola (*Brassica napus* L.) (Rubio et al., 2020; Włóka et al., 2019), and chinese mustard [*Brassica juncea* (L.) Czern] (Chen et al., 2020; Soares et al., 2020).

It is important to notice that phytoremediation can be considered a low-cost technique compared to other decontamination techniques (Nedjimi, 2021; YAN et al., 2020; Tavares, 2009). For example, it is possible to achieve an economic surplus within seven years after its implementation (Wan et al., 2016). However, there is a lack of literature that addresses this subject, especially regarding costs and feasibility applicability. In this sense, becomes alarming contamination cases in farmlands without scientific support to manage decontamination.

Therefore, in this study, we present a comprehensive hypothetical scenario in brazilian farmland polluted with of HMs to estimate the phytoremediation technique economical costs analysis.

MATERIAL AND METHODS

Study Area and Plant Material

Our study investigated HMs soil contaminated agricultural areas (sugarcane farm) in the region of Mogi Guaçu (São Paulo state, Brazil) reported by Environmental Company of the State of São Paulo or *CETESB* (Companhia de Tecnologia de Saneamento Ambiental do Estado de São Paulo, 2020). We performed the return rate calculation methods for the sugarcane crop

(*Saccharum officinarum* L.) according to the National Company of Supplying or *CONAB* (Companhia Nacional de Abastecimento, 2021). The plant species *Brassica rapa* L. (turnip) was chosen as a 'phytoremediator plant model' for simulating our case study because possesses some interesting characteristics such as seed acquisition, climate adaptation, robust root system, HMs hyperaccumulate multiple, HMs stress tolerance, and management cultivation. Moreover, we considered carrying out two production cycles in the cultivation of turnip plants for performed pollutants phytoremediation (Zhang et al., 2021; Chen et al., 2020; Haider et al., 2021).

Path Planning Method and Farm Surveys

To perform production cost and profit calculations, we based on microeconomic and production cost concepts (Pindyck and Rubinfeld, 2013). In this way, to obtain production cost data for sugarcane, we applied surveys to producers, agricultural resellers, and bioenergy plants, achieving the results presented in Table 1. Concerning turnip, we were based on the literature and research with agricultural producers and resellers (Table 2). To obtain data on productivity and commercial value, we used databases from the Institute of Agricultural Economics or IEA (http://www.iea.agricultura.sp.gov.br/out/Bancodedados.php).

Data Analyses

To quantify the gross profit of sugarcane, we consider the following equation (Equation 1):

$$GP = AV \times CP \quad (1)$$

Table 1. Summary of sugarcane (*Saccharum officinarum* L.) production costs to one cycle production year.

Activity	Cost (ha)
Soil preparation *	US$56.41
Planting *	US$184.54
Fuel	US$7.82
Fertilizers	US$233.29
Herbicides	US$63.25
Fungicides	US$6.36
Inseticides	US$25.86
Harvesting, loading, transporting[1]	US$420.24
Cost for 1 ha	**US$997.79**
Cost for 100 ha	**US$99,779.17**

*Amortization of the value in five years, as the sugarcane crop is semi-perennial and its implementation cost can be diluted in its total production period. [1]outsourced activity.

Where GP is the gross profit; AV is the average productivity; SD is the commercialization price.

To calculate the annual net profit on the sugarcane farm we consider the cost and gross profit (Equation 2):

$$NP = GP - C \quad (2)$$

Where NP is the annual net profit; C is the cost; GP is the gross profit.

We consider that the sugarcane farm will experience an economic loss during the remediation period (Equation 3):

$$EL = NP \times t \quad (3)$$

Where EL is the economic loss; NP is the annual net profit; t is the evaluated time.

The calculation of the financial return was performed based on the concept of economic surplus and deficit (Equation 4):

$$ED = PC + EL \quad (4)$$

Where ED is the economic deficit; PC is the phytoremediation cost; EL is the economic loss.

Subsequently, to calculate the economic payback time, the estimated time for the agriculturist to cover the calculated economic deficit will be considered (Equation 5):

$$PB = ED / NP \quad (5)$$

Where PB is the economic payback time; ED is the economic deficit; NP is the annual net profit.

RESULTS

Consulting the IEA databases, we found that the average productivity (AV) of sugarcane in São Paulo is

Table 2. Implementation and conduction of phytoremediation technique used turnip plants (*Brassica rapa* L.)

Activity	Cost (ha)
Fuel	US$11.99
Seeds	US$61.13
Herbicides	US$19.7
Inseticides	US$20.63
Fungicides	US$6.38
Fertilizers	US$133.71
Harvest	US$127.00
Cost for 1 ha	**US$380.51**
Cost for 100 ha	**US$38,050.65**

81.38 t/ha and the commercialization price (CP) is US$ 14.46/t (for September/2020) (Iea, 2021). Thus, following Equation 1, we have that (Equation 6):

$$GP = AV \times CP$$

$$GP = 81.38t / ha \times 14.46 / t \tag{6}$$

$$GP = US\$1,176.61/ha$$

Thus, GP for 1ha is US$ 1,176.61/ha, therefore, for 100ha GP is US$ 117,660.59 per productive year. After that, by gathering data from producers, local traders, and bioenergy plants, we quantify that sugarcane production will have an average annual production cost (C) average of US$99,779.17 (US$997.79/ha) (Table 1). It is worth mentioning that the amount related to Harvesting, loading, and transporting, shown in Table 1, is charged by the bioenergy plant that acquired the production, thus, it is an outsourced cost to the farmer.

We calculated the cost of performing phytoremediation after reading and critically analyzing some publications (Salton et al., 1995; Cremonez et al., 2013; Bassegio and Zanotto, 2020), and informal queries, from the use of the plant species phytoremediator turnip. The value found ranged around US$38,050.65 ($380.51/ha) (Table 2). However, in this hypothetical scenario, we consider the need to carry out the cultivation of turnip in two production cycles, reducing the levels of heavy metals in the soil - as indicated by Wan et al. (2016) - enabling the realization of commercial production. In this way, the cost of phytoremediation (PC) will be US$76,101.30.

It is noteworthy that in our hypothetical scenario, we considered that the farmer would already possess the necessary implements to carry out the phytoremediation, such as tractors, spray pumps, etc. Furthermore, we consider CETESB's management itinerary rules for contaminated areas, so that there are eight procedures for the implementation of the phytoremediation technique, such as (i) preliminary assessments; (ii) confirmatory investigation; (iii) prioritization, (iv) detailed investigation; (v) risk assessment, (vi) remediation investigation; (vii) remediation project and, finally, (viii) remediation (Companhia de Tecnologia de Saneamento Ambiental do Estado de São Paulo, 2001). Although there is no literature on the expected time to complete the phytoremediation script in full, we can speculate a total period of two (2) years required to carry out the script and one (1) year to carry out and conduct the phytoremediation. Thus, it would take three (3) years in all to solve the problem in the area.

Thus, the calculations of the annual net profit, economic losses, and economic deficit can be visualized in Figure 1.

After three years of phytoremediation implementation and conduction, it is expected that the contamination by HMs has been mitigated. Thus, the farm will be able to produce again, and the payback time (PB) can be shown in Figure 2.

Thereby, we state that the implementation and conduction of phytoremediation costs in agricultural areas are elevated (US$380.51/ha ~ 213% of the value collected per hectare in a productive year of sugarcane). In addition, the payback time is relatively high, estimated at 7.26 years (~ seven years).

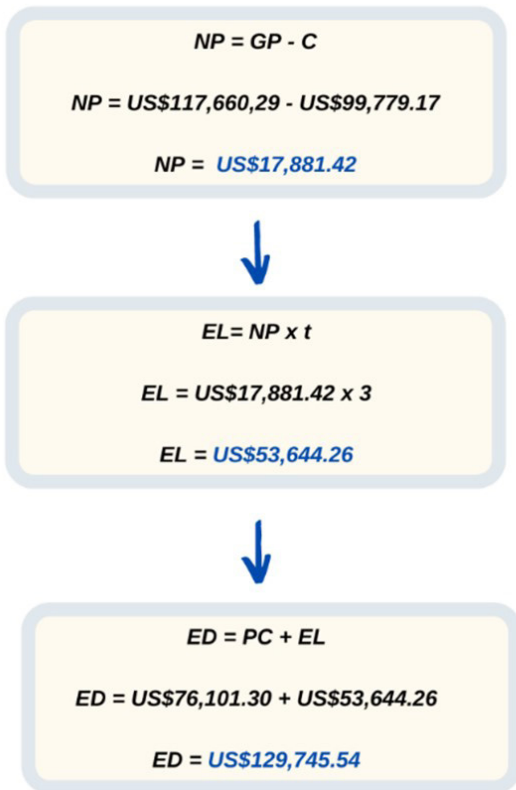

Figure 1. Calculations of annual net profit, economic losses, and economic deficit. (NP) net profit, (GP) gross profit, (C) costs, (EL) economic loss, (t) time, (ED) economic deficit, and (PC) phytoremediation costs.

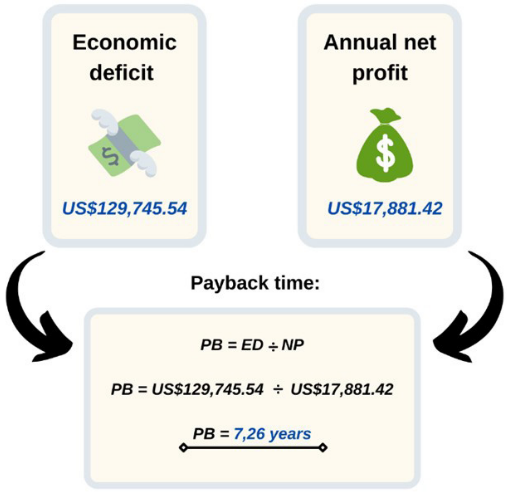

Figure 2. Calculation of the payback time of Brazilian farmland that performed phytoremediation to decontaminate soils with HMs. (PB) payback time, (ED) economic deficit, (NP) annual net profit.

DISCUSSION

Our hypothetical scenario allows us to state phytoremediation implementation and conduction costs for sugarcane farmland in the next years are mandatory to remove the HMs from the soil due to deleterious effects on plants, which will surely reduce the profits of an agriculturist. If this decontamination does not occur, commercial production to decrease drastically (Odoh et al., 2019; Haider et al., 2021; Wu et al., 2018).

Regarding data obtained on annual net profit and cost in the production of sugarcane, it is worth noticing that agricultural data obtained can be considered greater when compared to similar reports from previous years (Trevisan and Lima, 2015). Nevertheless, our Brazilian data survey was carried out in a COVID-19 (SARS-CoV-2) disease pandemic reality, which allows us to state that agricultural inputs faced high prices, largely due to the devaluation of the national currency (Brazilian real) against the US dollar. A calculated example is a pesticide price based on commercial 2,4-D (herbicide), from January 2020 to May 2021, even presented an increase of 46% in its value. In this period fertilizers formulated were even more expressive concerning herbicides, so, formulated 05-25-25 (NPK), presented a 93% increase (Iea, 2021). Thus, it is unsuitable to compare the values found in studies carried out before the period pandemic.

In addition to providing data on phytoremediation costs, our survey performed provides information that can help professional farmers make decisions in contaminated areas. So, as presented by Bernardino et al. (2016), phytoremediation is in full evolution in Brazil and has a great potential for development. It is worth mentioning that this work presented data referring to a specific situation, therefore, more studies must occur addressing phytoremediation in different areas, so that the scope of this technique can be defined.

It is worth mentioning that, during the research carried out with farmers, we identified that the implementation and conduction of phytoremediation in agricultural production areas can be considered “easy”. This is because, for the most part, the tools necessary for phytoremediation, such as tractors and agricultural implements, are equipment already owned by the farmers. In this way, there is no need for more investments and there is no difficulty in using them.

Furthermore, we can speculate that the period needed to achieve the payback time is approximately seven years after phytoremediation. According to Wan et al. (2016), when carrying out a study in the People’s Republic of China, they estimated that the benefits brought about by phytoremediation would pay the cost of its execution in up to seven years, among these benefits, which we can cite the annual agricultural production function, decrease in human income and ecosystem service function. Besides, the literature addresses the phytoremediation economic feasibility of equalizing the implementing initial costs in seven years.

CONCLUSION

The phytoremediation technique is relatively expensive to sugarcane farms polluted with HMs. We found a one-year economic loss of US$17,660.29 and a 3-year economic deficit of US$53,644.29. In our hypothetical scenario of sugarcane production, we calculated an annual net income of US$17,660.29, the financial payback time is approximately 7 years. Furthermore, phytoremediation can be considered a technique with “easy” application and conduction. Thus, we consider that it is economically viable and applicable for decontamination and soil conservation in the mentioned situation.

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