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THE PROSPECTS OF PHYTOREMEDIATION WITH CANNABIS SATIVA L. A REVIEW

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Abstract: The rapid population growth, urbanisation, and industrialisation as well as modern agricultural practices, have resulted in production of large volumes of various kinds of wastes that pollute the environment, especially soil. Traditional disposal of contaminated soil includes landfill and incineration. However, these techniques can be very onerous and are not effective at remediating the contaminated material. Phytoremediation is a strongly emerging technology for remediation of contaminated soil and, water, and sediment in an in-situ manner. It has been the relatively low cost of phytoremediation, when compared with that of treatments involving excavation and incineration make it a very reasonable technology. Hemp, scientifically referred to as *Cannabis sativa L.*, is a controversial herb in all spheres of society. While the plant is praised for its therapeutic and perhaps prophylactic properties against several ailments, hemp has also found a place in bioremediation, with applications that include ridding environments of biological and chemical contaminants, particularly in wastewater and solid waste. The following account appraises the known and potential applications of hemp in environmental remediation. Studies have shown that *C. sativa L.* can take up and accumulate heavy metals in its tissues and showed a very high tolerance to diverse contaminants. The specific mechanisms that hemp employs in the bioremediation processes include: (i) phytoextraction, (ii) rhizofiltration, (iii) phytodegradation and (iv) phytovolatilisation. Based on the novelty of applications of hemp in bioremediation, further research is urged to unravel the full potential of the plant in all spheres of environmental management.

Keywords: Solid waste; phytoremediation; *Cannabis sativa L.*; hemp; heavy metals; leachate.

UPORABA KONOPLJE CANNABIS SATIVA L. ZA FITOREMEDIACIJO TAL: PREGLED LITERATURE

Povzetek: Hitro rastoče prebivalstvo, urbanizacija in industrializacija ter sodobno kmetijstvo proizvajajo ogromne količine raznoraznih odpadkov, ki onesnažujejo in obremenjujejo okolje, predvsem zemljine oz. tla. Tradicionalni postopki obdelave in sanacije onesnaženih tal, kot sta odlaganje in sežig, so zelo zahtevni in neučinkoviti pri sanaciji kontaminiranega materiala oz. snovi. V ta namen znanstveniki razvijajo nove metode in postopke, ki bi bili v tem pogledu bolj učinkoviti in manj zahtevni. Fitoremediacija je ena taka metoda, ki učinkovito pomaga pri sanaciji onesnaženih tal ter vode in usedlin na »in situ« način (slov. »na kraju samem«). Še ena prednost fitoremediacije je ta, da so stroški v primerjavi s tradicionalnim postopkom obdelave nizki. Konoplja, znanstveno imenovana *Cannabis sativa L.*, ki po eni strani velja za zelo kontroverzno rastlino, po drugi strani pa je mednarodno priznana zaradi svojih terapevtskih in morda profilaktičnih lastnosti, ki pomagajo v boju proti številnim boleznim, je sedaj našla svoje mesto tudi v bioremediaciji z aplikacijami, ki vključujejo odstranjevanje bioloških in kemičnih onesnaževalcev iz okolja, odpadnih voda in trdnih odpadkov. Pričujoči članek obravnava že obstoječe in potencialne postopke uporabe konoplje za sanacijo okolja. Študije kažejo, da rastlinska tkiva *C. sativa L.* absorbirajo in akumulirajo težke kovine ter da je konoplja zelo odporna na različne onesnaževalce. Posebni mehanizmi, ki jih konoplja uporablja v procesih bioremediacije, so: (i) fitoekstrakcija, (ii) rizofiltracija, (iii) fitodegradacija in (iv) fitovolatilizacija. Da bi odkrili celoten potencial rastline na vseh področjih upravljanja z okoljem so potrebne nadaljnje raziskave in študije.

Ključne besede: trdni odpadki, fitoremediacija, *Cannabis sativa L.*, konoplja, težke kovine, izcedne vode.

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Introduction

Soil pollution is a serious environmental problem, especially in highly industrialised western countries (Di et al., 2020). The rapid population growth, urbanisation and industrialisation as well as modern agricultural practices, have resulted in production of large volumes of various kinds of wastes containing both organic and inorganic compounds (Bakhshoodeh et al., 2020; Kumar et al., 2017; Singh et al., 2016). Human activities such as release of industrial effluents, municipal wastes and waste sludge is highly implicated in contamination of soil (Asad et al., 2015). In addition, mining and smelting of metalliferous ores as well as the use of pesticides and fertilizers, have reportedly resulted in contamination of large areas of land with heavy metals (Singh et al., 2016). Although some heavy metals including Fe, Mn, Zn, Cu, Mg, Mo, and Ni are necessary for plant growth, they are detrimental to the environment at high concentrations (Husain et al., 2019). The persistent nature of the heavy metals and their leaching into the environment is a serious health threat to living organisms and the environment (Citterio et al., 2003b; Asad et al., 2015; Singh et al., 2016; Kumar et al., 2017; Hussain et al., 2019). Studies have shown that heavy metals negatively affect the nervous, renal, gastrointestinal, reproductive, cardiovascular, skeletal and muscular systems of organisms (Di et al., 2020).

The rapid growth in human population and associated consumptive lifestyle have caused a significant growth in the volume of municipal solid waste (MSW) generated by communities (Bakhshoodeh et al., 2020). Globally, there is an unprecedented increase in the volume MSW and its generation is estimated to increase to 3.4 billion tons per annum in 2050 (Kaza et al., 2018). In most developing countries, landfilling is the common method for disposal of almost all the generated solid waste (Aljaradin, 2012). Percolation of precipitation through the landfills and internal biological processes generates leachate which contains a mixture of dissolved organic and inorganic compounds including heavy metals (cadmium, chromium, copper, lead, nickel and zinc) and xenobiotic compounds (Jones et al., 2006; Rosenkranz, 2013). The leachate migrate through the soil spreading the contaminants to the surrounding ecosystems (Tangahu et al., 2011). The dissolved organic and inorganic compounds are usually in very high concentrations and are a threat to the environment and human health (Husain et al., 2019; Saxena et al., 2019). There is therefore a need for appropriate treatment of the leachate before releasing it into the environment.

In as much as most countries, both developing and developed, prioritise management of contaminated soils, the sustainability of the remediation methods in place is a challenge. There are several remediation technologies that were developed and applied in the remediation of ecosystems contaminated with toxic wastes. Common technologies for toxic pollutant removal include stabilization/solidification, incineration, solvent extraction, soil washing, thermal treatment, chemical treatment, air sparging and verification (Kumar et al., 2017). However most of these technologies are costly, technically difficult, environmentally unsustainable and perform below expectation (Tangahu et al., 2011). For example remediation of heavy metal contaminated ecosystems using excavation and disposal to a landfill method is a matter of shifting the contamination problem to another site (Tangahu et al., 2011). There is need to develop robust technologies that are efficient, cost effective, technically easy and environmentally sustainable for the remediation of contaminated environments such as phytoremediation.

Phytoremediation, a technology which uses plants and their associated rhizospheric microorganisms to remove, degrade, or immobilize various contaminants from polluted soils (Marques et al., 2009), has emerged as promising alternative measure for remediation of contaminated soils. The technology uses naturally occurring processes involving plants and their microbial rhizosphere organisms to sequester, degrade or immobilize or detoxify pollutants in the remediation of contaminated soils (Marques et al., 2009; Rosenkranz, 2013; Gomes, 2012; Kumar et al., 2017). The technology is cost effective and environmentally friendly and has gained environmentalists interest as a sustainable approach for eradicating toxic soil contaminants (Tangahu et al., 2011; Kumar et al., 2017; Husain et al., 2019). Several studies investigated the potential of various plants to remove toxic substances from contaminated soils. Several the studied plants have displayed potential for application in phytoremediation (Husain et al., 2019) with more than 400 species being able to absorb and accumulate metals (Asad et al., 2015). In addition, a wide range of pollutants like inorganic chemicals including heavy metals and metalloids, many organic substances including persistent organic pollutants and radioactive materials have reportedly been removed by plants from contaminated environments (Pandey et al., 2016, Yao, 2017, Vaverkova et al., 2017). However there are disadvantages in the use of plants in remediation as the process quite slow and usually takes several years (Shi & Cai, 2009) due to low biomass and root penetration depth of selected plants, in some cases (Citterio et al., 2003b). Nevertheless, studies reported in recent years have focused on studying the phytoextraction capabilities of species with a high production capacity which could compensate for the lower accumulation levels through higher biomass production (Di et al., 2020). Researchers have shown great interest in *Cannabis sativa* L. and several studies have investigated its ecoremediation potential (Citterio et al., 2003b; Citterio et al. 2005; Hussain et al., 2019; Galić et al., 2019; Di et al., 2020).

Hemp/marijuana, scientifically referred to as *Cannabis sativa* L., is a controversial plant in all spheres of society that has been cultivated for over 6000 years (Vaverkova et al., 2017). While the plant is praised for its known and novel therapeutic and perhaps prophylactic properties against several ailments, including cancer, lupus, asthma, rheumatoid arthritis, depression, and hypertension (Piluzza et al.,

2013; Caffarel et al. (2012), the herb has gained interest for its psychoactive properties, hence a major drug of (ab)use. *Cannabis sativa* L. has proved to be a major source of materials of industrial importance, as a source of seed oil, industrial fibre (Musio, Müssig, & Amaducci, 2018), livestock feed, food as well as for recreation, religious and spiritual practices (Kumar et al., 2017), paper-making, cosmetics, personal care and pharmaceutical product manufacturing (Vaverkova et al., 2017) and lately the plant has found a place in the field of environmental protection. Of interest in the field of environmental protection, is the use of hemp in bioremediation, with applications that include ridding environments of organic and inorganic contaminants. Interestingly the plant has a rapid growth, high biomass production, extensive and deep root system, short growing cycle, decreased need for pesticides, high tolerance to drought and heavy metal stress as well as high metals accumulating capability which makes it an ideal candidate for phytoremediation studies (Ahmad et al., 2015; Husain et al., 2019; Pietrini et al., 2019; Di et al., 2020). Against this background, we evaluate organic and inorganic contaminant removal of *Cannabis sativa* L. and its potential application in bioremediation of sites contaminated with toxic or hazardous anthropogenic wastes.

Cannabis sativa L. and remediation of heavy metal contaminated soils

Pollution of the environment with heavy metals has dramatically accelerated during the last century (Barazani et al., 2004; Di et al., 2020) as humans began to engage in mining, smelting, manufacturing and disposal of municipal waste (Ayers, 1992). Soil contamination by heavy metals is a major problem to the world today (Ahmad et al., 2015). Heavy metals are known to persist in the environment since they are not chemically or biologically degradable (Barazani et al., 2004; Marques et al., 2009). Several studies have explored the use of *C. sativa* L. in the remediation of heavy metal contaminated soils. Uptake and accumulation of a variety of heavy metals including nickel (Ni), lead (Pb), cadmium (Cd), zinc (Zn), copper (Cu) and chromium (Cr) in hemp tissues have been reported (Linger et al., 2002; Kos et al., 2003; Piotrowsk-Cyplik and Czarnecki, 2003; Tlustoš et al., 2006; Ahmad et al., 2015; Linger et al., 2005). A study by Linger et al., (2002), in Germany, examined the capability of *C. sativa* L. to decontaminate heavy metal polluted soils. Field based experiments using soil polluted with sewage sludge containing Cd, Ni and Pb revealed that hemp can indeed take up the heavy metals and distribute them throughout the tissues (seeds, leaves, fibres and hurds).

With regards to Cd, Linger et al., (2002) reported that *C. cannabis* L. extracted approximately 120 g per hectare (ha) over a period of 3-4 months. The concentration of these metals differed between tissues and the highest concentration was recovered in leaves. However, in another study, Linger et al., (2005), using pot experiments in a greenhouse, to investigate phytoextraction of Cd by *C. sativa* L., revealed that the roots accumulated the highest Cd concentrations, reaching a maximum of 830 mg kg⁻¹ dry mass after 24 days with stems and leaves accumulating up to 87 and 68 mg kg⁻¹, respectively. A similar study was conducted by Ahmad et al., (2015) in Pakistan, focusing on phytoextraction of Cu, Cd and Ni by hemp growing on heavy metal contaminated soil. Heavy metals accumulation rates of 1530 mg kg⁻¹ Cu, 151 mg kg⁻¹ Cd and 123 mg kg⁻¹ Ni were recorded, making the plant a suitable candidate for remediation of soils contaminated with these metals. For each heavy metal, the concentration recovered from tissues differed and Clitterio et al., (2003b) reveals that, the order of accumulation by *Cannabis sativa* L. is Cd>Ni>Cr. Contrary to the findings by Clitterio et al., (2003b), a recent field study, at Mazovian Agricultural Advisory Centre in Poland, concentration of heavy metal accumulation by hemp was highest for Fe followed by Mn, Zn, Cr, Cu, Ni, and then Cd (Under & Conditions, 2020). Over all, some concentrations of heavy metals recovered from the tissues of hemp reported, qualify the plant for hyperaccumulation (Under & Conditions, 2020). More investigations are required as there are reports to the contrary. However, studies have demonstrated that hemp meets the criterion of a phytoextractor related to the heavy metal transfer from root to shoot.

The distribution of heavy metals within *C. sativa* L. tissues are contradictory. A field study by Angelova et al., (2004) showed that heavy metals distribution along the plant axis is selective and the contents in hemp decreased in the following order: roots > stems > leaves > seeds. These findings are consistent with results by Ahmad et al., (2015). Shi et al., (2012) used pot tests to investigate Cd accumulation potential of eighteen hemp cultivars under greenhouse conditions at Huaibei Normal University in China. Cadmium accumulation rates and distribution in root and shoot tissues of the plant were shown to be significantly different ($p < 0.001$). Hemp roots were shown to accumulate high Cd concentrations (217–481 mg kg⁻¹) compared to the shoots (11.4–24.9 mg kg⁻¹). This trend was also observed for the removal of radioactive materials from the environment by *C. sativa* L. A study by Hoseini et al., (2012) in Tehran, Iran, confirms that roots absorb the highest concentrations of strontium with 45% absorbed by the roots, 40% by the stem, and 15% by the leaves. This is in contrast to earlier reports by Linger et al., (2002) that high concentrations of Cd accumulate in leaves. It is however advantageous for heavy metals to be highly concentrated in the above ground tissues as harvesting of these parts ensure removal of the contaminants from the environment.

Regardless of the discrepancies in the distribution of heavy metal within the *C. sativa* L., tissues, the plant have generally shown tolerance to heavily polluted soils (Shi & Cai, 2009; Shi et al., 2012). Tolerance of the plant to heavy metals depends on the species ability to activate molecular mechanisms, for example metal sequestration in the cell wall and/or in vacuoles (Citterio et al., 2003b). This is based on genetic, morphological, physiological and anatomical characteristics of the plant (Galić et al., 2019). Although Linger et al.,

(2002) reported that increasing concentrations of metals in soils leads to increased translocation from roots to leaves and shoots of hemp plants, Tlustoš et al., (2006) observed that increasing the concentration of heavy metals in soil increases plant growth inhibition due to element toxicity. However *C. sativa* L. roots demonstrated a strong resistance to heavy metals as well as hyperaccumulator like potential (more than 100 mg/kg Cd in dry tissue) (Girdhar & Raj, 2014). In 2005 Linger et al., (2005) investigated the effects of different cadmium concentrations on *C. sativa* L. growth (i.e. on roots, stem and leaves) and on photosynthesis. Study reports high tolerance to cadmium (>800 mg of Cd kg⁻¹(d.m)) of roots and no major effect on *C. sativa* L. growth. However, Cd concentrations of 50-100 mgkg⁻¹(d.m) adversely effected the viability and vitality of leaves and stems. The high Cd concentration affected chlorophyll synthesis as well the photosynthesis machinery lowering overall plant productivity (Linger et al., 2005). Plants grown in soil with high Cd concentration (71.7 ± 8.2 mg (Cd) kg⁻¹(soil), showed very strong growth inhibition, necrosis and most plants survived for 4 to 5 weeks post sowing. However, pot experiments conducted by Shu et al., (2012) observed that most hemp cultivars except USO-31, Shenyang, Shengmu, and Yangcheng, could tolerate 25 mg Cd kg⁻¹ soil stress and therefore can be cultivated in Cd contaminated soils. Generally, results reported by Di et al., (2020) confirm that soil heavy metal concentrations do not significantly interfere with hemp growth. This further confirms the suitability of the various cultivars suitable for phytoremediation of heavy metal contaminated soils.

The high tolerance of hemp to heavy metals reported could be attributable to presence of heavy metal genes (*GSR* and *PLDα*) (Citterio et al., 2003b; Ahmad et al., 2015). A study by Linger (2005) showed that hemp is a Cd-tolerant plant, with strong resistant roots and is capable of long-term acclimation. Hemp plants activate mechanisms that prevent damage such as production of glutathione and phytochelatins which inactivate excess of absorbed metals (Citterio et al., 2003b). Phytochelatins, synthesised in the cytosol, are involved in the formation of ligand complexes with metals which are then sequestered into vacuoles (Girdhar & Raj, 2014). With regards to Cd, Angelova et al., (2004) found that that some genotypes respond sensitively to Cd changes in the soil, with increased Cd concentration in soil causing its increased transport from roots to above-grounds plant parts. This mechanism ensures that more Cd can be taken up from the soil.

Use of hemp in remediation of landfill leachate

Landfills are considered a convenient and cost-effective method for solid waste management in many countries across the globe. Of note is the fact that solid waste materials in a landfill undergo physical, chemical, and biological transformation which produces leachates (Zloch et al., 2017). The leachate, which is a major source of pollution, commonly contains large amounts of organic matter, ammonium, heavy metals, and chlorinated organic and inorganic salts, which in turn are a major threat to soils and water sources in the vicinity of the landfill (Vaverková1 et al., 2017).

Hemp have reportedly been used in the treatment of landfill leachate. Studies indicates that leachate can induce both positive and negative responses in the plants (Mor et al., 2013). In 2017, Vaverkova et al., (2017), evaluated the potential of *C. sativa* L. for toxicity removal from landfill leachate. Laboratory based hydroponic experiments were carried out using raw leachate collected from the pond of untreated leachate at a sanitary landfill in Czech Republic to investigate effects of different concentrations of leachate on seed germination and seedling growth of three hemp cultivars. Study results indicate that leachate can severely inhibit plant growth particularly concentrations greater than 90%. However, leachate concentrations lower than 25% stimulated growth. Furthermore, the response to leachate toxicity differed. The toxic effect of leachate on plants depends on several factors including the plant species and the composition of the leachate. Leachate contains a wide range of inorganic and xenobiotic organic (XOCs) compounds like hydrophobic, volatile, aromatic, and aliphatic organic substances, (Vaverkova et al., (2017). No studies to show the toxicity of the individual components on hemp plants were found.

A recent field-based study by Zloch et al., 2017 investigated reaction of two *C. sativa* L. varieties (Bialobrzeskie and Monoicaon) to leachate irrigations. Comparisons were made in terms of growth between plants that were irrigated with leachate and those with rainwater, the controls. Study results indicate that Bialobrzeskie and Monoicaon varieties watered with rainwater grew 26% and 34% taller on average respectively, than plants watered with leachate. This result supports earlier results by Vaverkova et al., (2017) indicating that leachate inhibit growth of *C. sativa* L. However, growth inhibition and or toxicity may not be the same in seeds, seedling and older plants. Further investigations are therefore necessary on the toxicity of leachate on hemp plants, that is, in terms which cultivar can tolerate leachate toxicity and toxic substance removal from leachate. Although results indicate high levels of inhibition to growth of hemp, other studies conducted revealed that it can accumulate a considerable amount of heavy metals making it a good candidate for remediation.

Several studies explored the potential use of various plants in environmental protection through phytoremediation. Indications are that plants can be used sustainably to decontaminate polluted environments.

Mechanisms for Heavy Metal Removal

Heavy metal uptake and accumulation capabilities of plants cannot be explained by passive ion uptake and the metal tolerance genes only. There are many more mechanisms involved in phytoremediation including, phytoextraction, phytovolatilization, rhizofiltration, and phytodegradation (Jones et al., 2006; Rosenkranz, 2013; Girdhar & Raj, 2014). Plants use phytoextraction, a process of extraction of pollutants from the soil and accumulation in the plant tissue, to remove metals from the environment (Rosenkranz, 2013). The metals enter the roots either by following the apoplastic pathway or symplastic pathway. However, the uptake and accumulation of metals is influenced by several factors.

Soil factors, including pH, soil organic matter content, redox potential, clay content, cation exchange capacity, nutrient balance, concentrations of other trace elements in soil, soil moisture and soil temperature influence phytoextraction in plants (Galić, , 2019; Di et al., 2020). Soil pH affects mobility and bioavailability of metals in the soil solution (Husain et al., 2019). Study by Pietrini et al., (2019) on metal absorption by hemp showed that alkaline conditions negatively affected the mobility and bioavailability of metals thereby reducing their uptake. Suitable pH is therefore critical, for example most heavy metals, including Cd, Cr, Cu, Ni, Pb, and Zn, reportedly become more bioavailable under acidic soil conditions (Galić et al., 2019).

Besides pH, heavy metal removal from the soil is reportedly enhanced by biodegradable chelating agents that increase bioavailability of metal elements (Malhotra et al., 2014). A study conducted by Kos et al., (2003) in Slovenia investigated the effects of chelates ethylenediamine-tetracetic acid (EDTA) and ethylenediamine-disuccinic acid (EDDS) on phytoextraction of Pb, Zn and Cd by fourteen plant species. EDDS significantly improved phytoextraction in *C. sativa* L. but was generally less effective in other tested plants. In the case of Pb, phytoextraction potential 26.3 kg/ha were recorded for *C. sativa* L., which was much higher than 126 g/ha as reported by Linger et al., (2002). This improves the prospects of hemp as a remediation agent. Further investigations are needed on this aspect to improve phytoextraction of heavy metals even in the management of solid waste and wastewater.

Conclusion

Phytoremediation is a fast developing field and metals uptake by plants seems to be an economic and sustainable way to remediate contaminated environment. Evidence from the studies above indicates that *C. sativa* L. (hemp) can tolerate heavy metals thus can grow in heavy metal contaminated soils removing metal contaminants from soils and landfill leachate. The improved uptake of metals due to application of chelating agents and the presence of metal tolerance genes affirms the suitability of this plant species for phytoremediation. Furthermore, hemp can accumulate significant amounts of heavy metals in its tissues due to its high biomass productivity and deep roots. This makes it a good candidate for phytoremediation. Although little research has been done in the application of phytoremediation of landfill leachate, the potential of hemp in cleaning up contaminants from leachate is promising. Based on the novelty of applications of hemp in bioremediation, further research is urged to unravel the full potential of the plant in all spheres of environmental management.

References:

1. Ahmad, R., Tehsin, Z., Tanvir-Malik, S.T., Asad, S.A., Shahzad, M., Bilal, M., Shah, M.M., & Khan, S.A. (2016). Phytoremediation potential of hemp (*Cannabis sativa* L.): identification and characterization of heavy metals responsive genes. *Clean-Soil Air Water*, 44, 195–201.
2. Aljaradin, M. (2012). Environmental Impact of Municipal Solid Waste Landfills in Semi-Arid Climates - Case Study – Jordan. *The Open Waste Management Journal*, 5(1), 28–39. <https://doi.org/10.2174/1876400201205010028>
3. Amaducci, S., Zatta, A., Raffanini, M., & Venturi, G. (2008). Characterisation of hemp (*Cannabis sativa* L.) roots under different growing conditions. *Plant and Soil*, 313(1–2), 227–235. <https://doi.org/10.1007/s11104-008-9695-0>
4. Angelova, V., Ivanova, R., Delibaltova, V., & Ivanov, K. (2004). *Bio-accumulation and distribution of heavy metals in fibre crops (flax , cotton and hemp)*. 19, 197–205. <https://doi.org/10.1016/j.indcrop.2003.10.001>
5. Asad, S. A., Muhammad, S., & Shah, M. M. (2015). *Phytoremediation Potential of Hemp (Cannabis sativa L.): Identification and Characterization of Heavy Metals Responsive Genes*. (November 2017). <https://doi.org/10.1002/clen.201500117>
6. Ayers, R.U. (1992) Toxic heavy metals, materials cycle optimization. *Proc. Nat. Sci. USA* 89, 815-820.
7. Bakhshoodeh, R., Alavi, N., Oldham, C., Santos, R. M., Babaei, A. A., Vymazal, J., & Paydary, P. (2020). Constructed wetlands for landfill leachate treatment: A review. *Ecological Engineering*, 146(May 2019). <https://doi.org/10.1016/j.ecoleng.2020.105725>
8. Barazani, O., Sathiyamoorthy, P., Manandhar, U., Vulkan, R., & Gola-Goldhirsh, A. (2004). Heavy metal accumulation by *Nicotiana glauca* Graham in a solid waste disposal site. *Chemosphere*, 54, 867-872.
9. Caffarel MM, Andradas C, Pe´rez-Go´mez E, Guzm´an M, Sa´nchez C (2012) Cannabinoids: a new hope for breast cancer therapy? *Cancer Treat Rev* 38:911–918
10. Citterio, S., Santagostino, A., Fumagalli, P., Prato, N., Ranalli, P., & Sgorbati, S. (2003a). Heavy metal tolerance and accumulation of Cd, Cr and Ni by *Cannabis sativa* L. *Plant and Soil*, 256(2), 243–252. <https://doi.org/10.1023/A:1026113905129>
11. Citterio, S., Santagostino, A., Fumagalli, P., Prato, N., Ranalli, P., & Sgorbati, S. (2003b). *Heavy metal tolerance and accumulation of Cd , Cr and Ni by Cannabis sativa L.* (2001), 243–252.

12. Citterio, S., Santagostino, A., Fumagalli, P., Prato, N., Ranalli, P., & Sgorbati, S. (2003c). *Heavy metal tolerance and accumulation of Cd, Cr and Ni by Cannabis sativa L.* Author (s): Sandra Citterio, Angela Santagostino, Pietro Fumagalli, Nadia Prato, Paolo Ranalli and Sergio Sgorbati Published by: Springer Stable URL: [http://www.jstor.org/256\(2\), 243-252](http://www.jstor.org/256(2), 243-252).
13. Di, D., Delle, S., Vegetali, P., Suolo, D., Ambiente, E. D., Candito, M. Di, ... Re, L. D. (2020). *Heavy metal tolerance and uptake of Cd, Pb and Tl by hemp.* 18(3), 138–144.
14. Galić, M., Perčin, A., Zgorelec, Ž., & Kisić, I. (2019). Evaluation of heavy metals accumulation potential of hemp (*Cannabis sativa* L.). *Journal of Central European Agriculture*, 20(2), 700–711. <https://doi.org/10.5513/JCEA01/20.2.2201>
15. Girdhar, M., & Raj, N. (2014). *Comparative assessment for hyperaccumulatory and phytoremediation capability of three wild weeds.* 579–589. <https://doi.org/10.1007/s13205-014-0194-0>
16. Gomes, H.I. (2012) Phytoremediation for bioenergy challenges and opportunities. *Environmental Technology Reviews*, 1(1), 59-66.
17. Hoseini, P. S., Poursafa, P., Moattar, F., Amin, M. M., & Rezaei, A. H. (2012). *Ability of phytoremediation for absorption of strontium and cesium from soils using Cannabis sativa.* 1(2), 1–5. <https://doi.org/10.4103/2277-9183.96004>
18. Husain, R., Weeden, H., Bogush, D., Deguchi, M., Soliman, M., Potlakayala, S., ... Id, S. R. (2019). *Enhanced tolerance of industrial hemp (Cannabis sativa L.) plants on abandoned mine land soil leads to overexpression of cannabinoids.* 1–14.
19. Jones, D. L., Williamson, K. L., & Owen, A. G. (2006). Phytoremediation of landfill leachate. *Waste Management*, 26(8), 825–837. <https://doi.org/10.1016/j.wasman.2005.06.014>
20. Kos, B., Grčman, H., & Leštan, D. (2003). Phytoextraction of lead, zinc and cadmium from soil by selected plants. *Plant Soil Environ*, 49(12), 548–553
21. Kumar, S., Singh, R., Kumar, V., & Rani, A. (2017). *Cannabis sativa: A Plant Suitable for Phytoremediation and Bioenergy Production.* (May 2018). <https://doi.org/10.1007/978-981-10-3084-0>
22. Linger, P., Mussig, J., Fischer, H., & Kobert, J. (2002). Industrial hemp (*Cannabis sativa* L.) growing on heavy metal contaminated soil: fibre quality and phytoremediation potential. *Industr. Crops Protect*, 16, 33–42.
23. Linger, P., Ostwald, A., Haensler, J. (2005): *Cannabis sativa L. growing on heavy metal contaminated soil: growth, cadmium uptake and photosynthesis.* *Biol. Plant*, 49, 567–576.
24. Losfeld, G., de la Blache, P. V., Escande, V., & Grison, C. (2012). Zinc hyperaccumulating plants as renewable resources for the chlorination process of alcohols. *Green Chemistry Letters and Reviews*, 5(3), 451–456. <https://doi.org/10.1080/17518253.2012.667157>
25. Mal Ihotra, R., Agarwal, S., & Gauba, P. (2014). Phytoremediation of Radioactive Metals. *Journal of Civil Engineering and Environmental Technology*, 1(5), 75 – 79.
26. Marques, A. P. G. C., Rangel, A. O. S. S., Castro, P. M. L., Marques, A. P. G. C., Rangel, A. O. S. S., & Castro, P. M. L. (2009). *Remediation of Heavy Metal Contaminated Soils : Phytoremediation as a Potentially Promising Clean-Up Technology Remediation of Heavy Metal Contaminated Soils : Phytoremediation as a Potentially Promising Clean-Up Technology* (Vol. 3389). <https://doi.org/10.1080/10643380701798272>
27. Mor, S., Kaur, K., & Khaiwal, R. (2013). Growth behaviour studies of bread wheat plant exposed to municipal landfill leachate. *J. Environ. Biol.* 34, 1083–1087.
28. Musio, S., Müssig, J., & Amaducci, S. (2018). *Optimizing Hemp Fiber Production for High Performance Composite Applications.* 9(November), 1–14. <https://doi.org/10.3389/fpls.2018.01702>
29. Pandey, V.C., Bajpai, O., & Singh, N. (2016). Energy crops in sustainable phytoremediation. *Renew. Sust. Energ. Rev.* 54, 58–73
30. Pietrini, F., Passatore, L., Patti, V., Francocci, F., Giovannozzi, A., & Zacchini, M. (2019). *Morpho-Physiological and Metal Accumulation Responses of Hemp Plants (Cannabis Sativa L.) Grown on Soil from an Agro-Industrial Contaminated Area.*
31. Piluzza, G., Delogu G., Cabras A., Marceddu S and Bullitta S (2013). Differentiation between fiber and drug types of hemp (*Cannabis sativa* L.) from a collection of wild and domesticated accessions. *Genet Resour Crop Evol*, 60:2331–2342
32. Piotrowska-Cyplik, A., and Czarnecki Z (2003) Phytoextraction of Heavy Metals by Hemp during Anaerobic Sewage Sludge Management in the Non-Industrial Sites. *Polish Journal of Environmental Studies*, 12, (6), 779-784.
33. Rosenkranz, T. (2013). Phytoremediation of landfill leachate by irrigation to willow short-rotation coppice. *Master's Thesis. Department of Crop Production Ecology. Faculty of Natural Resources and Agricultural Sciences. University.*
34. Shi, G., & Cai, Q. (2009). Cadmium tolerance and accumulation in eight potential energy crops. *Biotechnology Advances*, 27(5), 555–561. <https://doi.org/10.1016/j.biotechadv.2009.04.006>
35. Shi, G., Lui, C., Cui, M., Ma, Y & Cai, Q. (2012). Cadmium Tolerance and Bioaccumulation of 18 Hemp Accessions. *Appl Biochem Biotechnol*, 168, 163–173
36. Singh, S., Parihar, P., Singh, R., Singh, V. P., & Prasad, S. M. (2016). Heavy metal tolerance in plants: Role of transcriptomics, proteomics, metabolomics, and ionomics. *Frontiers in Plant Science*, 6(FEB2016), 1–36. <https://doi.org/10.3389/fpls.2015.01143>
37. Tangahu, B. V., Sheikh Abdullah, S. R., Basri, H., Idris, M., Anuar, N., & Mukhlisin, M. (2011). A review on heavy metals (As, Pb, and Hg) uptake by plants through phytoremediation. *International Journal of Chemical Engineering*, 2011. <https://doi.org/10.1155/2011/939161>
38. Tlustoš, P., Szakova, J., Hrubý, J., Hartman, I., Najmanová, J., Nedělník, J., Pavlíková, D., & Batysta, M. (2006). Removal of As, Cd, Pb, and Zn from contaminated soil by high biomass producing plants. *Plant Soil Environ*, 52(9), 413–423.
39. Under, P., & Conditions, F. (2020). *Hemp-Based Phytoaccumulation of Heavy Metals from Municipal Sewage Hemp - Based Phytoaccumulation of Heavy Metals from Municipal Sewage Sludge and Phosphogypsum Under Field Conditions.* (June). <https://doi.org/10.3390/agronomy10060907>
40. Va verková, M. D., Zloch, J., Adamcová, D., Radziemska, M., Vyhnanek, T., Trojan, V., Winkler, J, Đorđević, B., Elbl, J., & Brtnický, M. (2017) Landfill Leachate Effects on Germination and Seedling Growth of Hemp Cultivars (*Cannabis Sativa* L.) *Waste Biomass Valor.*
41. Yao, P. 2017. Perspectives on technology for landfill leachate treatment. *Arabian Journal of Chemistry*, 10(2), 2567±2574
42. Zloch, J., Mendel, P, Adamcova, D., Vyhnanek, T., Trojan, V., Winkler, J., Dordevic, B., Bjelkova, M., Radziemska, M., Brtnicky, M., Vaverkova, M.D. (2017). Use of hemp (*Cannabis sativa* L.) in management of landfill leachate: preliminary analysis and reaction on leachate irrigations.