Vetiver Grass (*Chrysopogon zizanoides* L.) in Phytoremediation

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The increase of the global population and the requirement of food production and agricultural development, combined with a lack of water resources, have led to human attention being drawn to unconventional water sources, including saline water and wastewater. Most unconventional water treatment methods are not cost-effective; however, researchers have become interested in the phytoremediation method due to its cost-efficient and eco-friendly removal of many pollutants. Research showed that due to its unique characteristics, vetiver grass can be useful in phytoremediation.

Keywords: phytoremediation ; vetiver grass ; root exude ; saline water

1. Phytoremediation

Various physical and chemical approaches are applied to the process of unconventional water treatment [1][2]; however, most of them are associated with both disadvantages and limitations, such as the production of toxic sludge [3], high costs [4], and incomplete target removal [5]. Therefore, researchers have turned their interest toward the biological technique due to its low cost, nature-mimicking, and practical [6] bioremediation. This technique is based on the biogeochemical cycles, which is applicable to soil, surface water, groundwater, sediments, as well as ecosystem restoration and cleanup [7][8]. Phytoremediation, bioleaching land farming, bioventing, bioreaction, composting bio augmentation rhizofiltration, and biostimulation are known as bioremediation technologies [9].

The developed application of green plants with the purpose of purification of polluted environments, including soil, water, and wastewater, is known as phytoremediation [10]. *"*Phytoremediation*"* comes from the Greek word "phyto" (meaning plant) and the Latin word "remedium", which, respectively, mean "plant" and "removal/correction". The process can be applied to the green restoring of polluted sites [9]. Moreover, it cannot have any environmental adverse effects due to its biological traits [11]. Phytoremediation can also be defined as a process whereby soil or water pollutants are degraded, extracted, or immobilized through the use of plants [3][7]. The process is associated with nonintrusiveness, aesthetical smoothing, as well as biodegradant effects on polluted sites [12]. The mentioned technique can be used in places with different weather conditions through an appropriate plant selection [9]. It is recommended that the plant selection procedure be carried out considering the adequate growth ability in polluted water and soil. Studies showed that even within one genus, the pollutant uptake varies between species [13]. It has been demonstrated that phytoremediation, in combination with the simultaneous application of minerals, can have a significant impact on its capacity [14].

Plants are capable of remediating contamination through a number of different mechanisms and paths, including those of the roots and those of the foliar surface. The active surface area of a plant in the phytoremediation process refers to the pollutants' directly connected plant parts, which contribute to the remediation. For the remediation of aquatic media, plant shoots [15] or roots [16] can be considered as the active parts of the plant. Highly active surface areas of plants can develop the efficiency of remediation through providing more sites of micro-organism absorption [17].

According to several investigations, unconventional water phytoremediation using various plants, including common reeds (*Phragmites australis*) [18], water hyacinth (*Eichhornia crasspies*) [19], water lettuce (*Pistia stratiotes*) [20], bulrush (Typha) [21], duckweed (Lemna) [22], pampas grass (*Cortaderia selloana*) [23], vetiver grass (Chrysopogon zizanoioides) [19][24][25][26], and Quinoa plant (*Chenopodium quinoa* willd) [27], could be a supplementary approach.

2. Mechanisms of Phytoremediation

In phytoremediation, a variety of phytotechniques may be used to ameliorate a wide variety of pollutants using a variety of mechanisms depending on the application. There are various phytoremediation methods, including phytoextraction, phytostabilization, phytovolatilization, rhizodegradation, phytodegradation, as well as rhizofiltration, investigated comprehensively in several studies [9][28].

According to the previous literature, the mechanism of decontaminating unconventional water by vetiver grass is usually phytoextraction. The vetiver root system is dense and can be grown up to 7 m. The pollutants can be adsorbed by the channels, and then transferred in the plasma membrane of the root [25]. To understand the mechanism of vetiver grass for the decontaminating of industrial wastewaters, two factors consisting of the bioaccumulation factor (*BAF*), and translocation factor (*TF*) were evaluated. The *BAF* and TF can be expressed by Equations (1) and (2), respectively.

$$BAF = \frac{C_{planttissue}}{C_{wastewater}} \tag{1}$$

$$TF = \frac{C_{shoot}}{C_{root}} \tag{2}$$

where Cplanttissue, Cshoot, and Croot are the concentration of the pollutant in the harvested plant tissue, shoots, and roots, respectively, and also Cwastewater

is the initial concentration of pollutant in the wastewater. Previous research indicated that both *BAF* and *TF* are greater than 1, indicating that phytoextraction is the main mechanism for the phytoremediation of pollutants in wastewater using vetiver grass [25].

3. Vetiver System

The vetiver system is based on the use of the Nash vetiver plant. First, it was developed in 1985 by the World Bank to protect India's soil and water [24]. The system contributes to the procedures of agricultural land management [8], environmental protection [29], soil and water conservation [30], infrastructure balancing [31], contamination management [26], as well as water and wastewater treatment [32][33][34]. The origin of the *Chryspogon zizanioides* species is in South India [35]. This plant is sterile, non-invasive, and propagated by dividing the plant [36]. The plants are grown according to various factors, including soil moisture, soil texture, temperature, and chemical traits of heavy metal concentration, salinity, as well as pH value. This plant is able to grow and survive in harsh environmental conditions. Even though vetiver grass is tropical grass, it can survive extremely cold temperatures. Under frost conditions, the plant's top growth dies back or becomes dormant; however, the underground growing points remain active. According to a comparison, it was found that severe frost at –14 °C could not affect vetiver growth in Australia, while it respectively survived briefly at –22 °C (−8 °F) and −10 °C in northern China and Georgia (USA) [36]. This plant is a 4-carbon (C4) plant with different anatomical features, such as the type of stomata and epidermal nature. Moreover, its cellular arrangement is different from other C4 plants. It could be the reason for the plant's survival under different severe conditions [36]. Furthermore, its by-products could be applied to make handicrafts, thatches, animal feed, manure, and organic compost if the plant does not accumulate heavy metals.

3.1. Genetic and Taxonomic Properties

The vetiver grass (*Chrysopogon zizanioides* L.) family is similar to that of maize, sorghum, sugarcane, and lemon grass. It is extensively found in South and Southeast Asia. Specifically, it is native to tropical and subtropical Indian areas. In addition to *Chrysopogon zizanioides* L., there are various accessions of *Vetiveria zizanioides* (*L. Nash*) and Vetiver species, including *Chrysopogon fulvus* (Spreng.), *C. gryllus*, *Sorghum bicolor* (L.), and *S. halepense* (L.). Due to the fact that Chrysopogon and Vetiveria could not be separated through Random Amplified Polymorphic DNAs (RAPDs), their genera are merged. *Vetiveria zizanioides* (*L. Nash*) is recently referred to as *Chrysopogon zizanioides* (*L. Roberty*), which contains chromosomes x = 5 and 10, as well as 2n = 20 and 40 [37].

3.2. Morphological Characteristics

This plant belongs to Poaceae family and is free of stolons or rhizomes. It contains voluminous roots with fine structures that lead to its fast growth, which can even be increased to a depth of 3 to 4 m during the first year [38]. The deep roots of the plant can cause its extreme resistant against drought and makes it hard to uproot in strong water currents and wind. The stems are stiff and erect, highly resistant to pests, diseases, and fires, which form dense hedges that act as sediment filters and water spreaders when planted closely together. After being buried in sediment, new roots grow from nodes and vetiver develops new shoots from its underground crown. Therefore, it will be resistant to fire, frost, traffic, as well as high grazing pressure [38].

3.3. Physiological Characteristics

Vetiver grass has the ability to handle extreme weather conditions, such as extended drought, flood, submersion, as well as severe temperatures ranging from −14 °C to +55 °C. After the above-mentioned extreme conditions, the process of plant recovery will occur immediately. It can simply tolerate extensive soil pH values without soil amendment ranging from 3.3 to 12.5. It is highly resistant to pesticides and herbicides and efficient in absorbing heavy metals and dissolved nutrient solutions within polluted water. It is also extremely tolerant against high acidity, alkalinity, salinity, sodicity, magnesium growing mediums, as well as Al, Mn, and heavy metals such as As, Cd, Cr, Ni, Pb, Hg, Se, and Zn [39][40].

3.4. Ecologic Properties

Vetiver is highly resistant against the above-mentioned extreme conditions; however, it is not tolerant against shade as it could be observed for most of tropical grasses. The shading effect decreases vetiver growth over time and, in extreme cases, it can even eradicate the plant. Due to the fact that the best growth condition for the plant is an open weed-free environment. Vetiver initially decreases erosion and stabilizes slopes, especially steep slopes. Consequently, micro-environment development occurs due to its nutrient and moisture conservation, which leads to the establishment of volunteered plants or sown seeds [36].

4. Vetiver System to Reduce/Eliminate Contaminants from Unconventional Water

The plant selection is crucial for a successful phytoremediation [41]. There are different types of aquatic plants that can absorb and eliminate pollutants [3], such as free-floating plants (*Pistia stratiotes*, *Salvinia molesta*, Lemna spp., *Azolla pinnata*, *Landoltia punctata*, *Spirodela polyrhiza*, *Marsilea mutica*, *Eichhornia crassipes*, and *Riccia fluitans*), submerged plants (*Hygrophilla corymbosa*, *Najas marina*, *Ruppia maritima*, *Hydrilla verticillata*, *Egeria densa*, *Vallisneria americana*, and *Myriophyllum aquaticum*), and emergent plants (*Distichlis spicata*, Cyperus spp., *Imperata cylindrical*, *Iris virginica*, *Nuphar lutea*, *Justicia americana*, *Diodia virginiana*, Nymphaea spp., Typha spp., *Phragmites autralis*, and *Hydrochloa caroliniensis*) [42].

Vetiver’s specific properties include the growth capability under undesirable conditions, deep long roots, fleshy leaves, root aroma, soil agglomeration that resulted from extreme root-based absorption, metal adsorption capability, as well as tolerance against inadequate climatic conditions. Therefore, it is considered as an appropriate candidate for bioremediation [43]. In fact, this plant can remove many pollutants from soil and water or even detoxify them in its own tissue. It is reported that vetiver grass can effectively treat contaminants, such as organic matter, nutrients, heavy metals, as well as aromatic mixtures that are highly tolerant against extreme weather conditions (cold, hot, flood, and water shortage). According to the reports, vetiver has the capability of remediating toxic heavy-metal-polluted soil and water [44], herbicides [45], petroleum hydrocarbons (PHCs) [46], nuclear waste [47], acid mine drainage [48], textile dyes [49], ciprofloxacin (CIP), and tetracycline (TTC) [50], as well as 3-nitro-1,2,4-triazol-5-one (NTO) [51]. According to the unique characteristics reported for vetiver grass in the previous sections, several recent studies used this plant species to remove or decrease pollutants in unconventional water.

5. Traditional and Medicinal Uses of Vetiver Grass

In addition to the use of vetiver grass in the above-mentioned parts, this plant has also had many traditional and medicinal uses. For example, vetiver grass is used to improve nausea and vomiting, relieve genital disorders, improve sperm quality, promote lactation, relieve pain, and reduce fatigue. More precisely, the root of this plant is used for the improvement of burns, as a blood purifier/for the enhancement of blood circulation, as a gastrointestinal system strengthener, for the improvement of cataract/convulsions [52], for the improvement of malarial fever [53][54], as a respiratory system strengthener, as an immunity enhancer [55], and its stem is used to improve urinary tract infections [56].

The leaves of this plant have also been used to remove parasitic infections in feed animals [57], and the mixture of its roots and leaves has been used as a pain reliever for rheumatoid arthritis, lumbago, and sprain [52]. Recently, the utility of vetiver grass as a green infrastructure tool for transportation planning to reduce the risks of erosion, landslides, and flooding was reported [58].

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