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RESEARCH THE CHARACTERISTICS OF DIOXIN–CONTAMINATED SOIL IN BIEN HOA AIRBASE, DONG NAI PROVINCE, AND THE IMPACT OF VETIVER GRASS ON THESE CHARACTERISTIC

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2. **Nguyen Thi Thanh Thao**, Nguyen Thi Loi, Dang Thi Huyen, Quach Duc Tin, Ngo Thi Thuy Huong (2023), "The correlation between the mineral and dioxins in the soil in Bien Hoa airbase, Dong Nai province", Environmental Journal, *series No. IV*, Page 10-15.

INTRODUCTION

1. The urgency of the subject

Dioxin contamination at Bien Hoa airbase due to the storage and handling of Agent Orange and other herbicides during the War between Vietnam and the US [1] [19]. The most significant incidents of herbicide spills into the environment at Bien Hoa airbase have been recorded. Contaminated areas from herbicides by spills are flushed with diesel fuel or water to divert the drainage flow into settling tanks or pits for incorporation into the soil [21].

Bien Hoa airbase has many lakes and ponds, and the terrain slopes towards surrounding residential areas, especially the Dong Nai River. Therefore, the possibility of spreading dioxin in soil to low-lying areas, ponds, and lakes and towards the Dong Nai River is extremely risk. In addition to the large amount of dioxin in Agent Orange, the herbicide is known to be a member of the group of organic substances that are difficult to decompose and contains a significant amount of metal [22]. Furthermore, some heavy metals, especially Cadmium (Cd), exist in Diesel oil [23]. These reasons are the potential causes of heavy metals remaining in dioxin-contaminated soil in the Bien Hoa airbase. Therefore, the presence of dioxin in soil must be prioritized, evaluated, and researched on a small scale. In addition, some heavy metals in the soil must also be evaluated and researched at the Bien Hoa airbase.

Phytoremediation of environmental pollutants was an effective remedial solution to mitigate pollutants (mainly heavy metals and organic matter) from contaminated soil and water, which minimally impacted the ecosystem [27-28]. Phytoremediation was both highly effective and resistant to high levels of pollution [30]. According to previous studies, Vetiver grass can treat pollution from persistent organic substances (POPs) such as 2,4,6 trinitrotoluene [31-32] and hydrocarbon molecules in gasoline and oil [33]. In addition, Vetiver grass can proliferate, creating dense foliage and an extensive root system, and can be suitable for immobilizing toxic chemicals [34]. Moreover, the level of dioxin emissions from some typical industries in Bien Hoa, Da Nang, and the North were recently studied [3]. Therefore, the application of phytoremediation technology to treat dioxin from emission sources is a requirement in the future.

As mentioned above, the Ph.D. student chose "Research on environmental characteristics of dioxin-contaminated soil at Bien Hoa airbase, Dong Nai, and the impact of Vetiver grass on these characteristics".

2. Objectives of the study

To determine the characteristics of the dioxin-contaminated soil environment and the impact of Vetiver grass on those characteristics, the content of the thesis presents the physical and chemical characteristics of the soil environment as well as presents the dioxin content and some heavy metals before and after planting Vetiver grass. In addition, the effectiveness of Vetiver grass in treating dioxin and some heavy metals is also considered, evaluated, and presented in the thesis. Therefore, the research objectives of the thesis include:

- ✓ Research and evaluate the environmental characteristics of dioxin-contaminated soil at BH airbase (Bien Hoa) by evaluating physicochemical parameters, particle composition distribution, and assessing dioxin content, and the content of some metals heavy species in the soil environment of the study area before planting Vetiver grass.
- ✓ Research and evaluate the impact of Vetiver grass on the environment, specifically dioxin-contaminated soil throughout the experimental time.

3. Objects and the scopes of the study

Research subjects: Dioxin-contaminated soil layer at Bien Hoa airbase, Dong Nai province.

Scope of the research: Southwest corner of Pacer Ivy runway area, Bien Hoa airbase, Dong Nai with 600m2 square area and soil layer research depth of 0.5m.

4. Contents

To complete the proposed research objectives, the content of the project needs to carry out the following:

- Research on physical and chemical characteristics of soil (Eh, Ec, pH, OC) in Pacer Ivy area, Bien Hoa airbase, Dong Nai province before and after treatment.

- Research and determine the dioxin content and the concentration of some heavy metals (Cd, Cr, Cu, Ni, Pb, and Zn) in soil in the Pacer Ivy area before and after treatment. The results are compared with Vietnam's Standards (QCVN 45:2012/BTNMT for dioxin; QCVN 03/MT:2023/BTNMT for heavy metals) and standards of some other organizations and countries such as WHO, Canada, and the EU.

- Evaluate the effectiveness of Vetiver grass in improving soil quality and reducing dioxin and heavy metal pollution in soil. And determine the time needed to effectively treat heavy metals and dioxins of Vetiver grass.

5. Arguments

Bien Hoa Military Airbase is one of the hot spots of dioxin contamination due to the war in Vietnam many decades ago. On the other hand, Bien Hoa airbase distributes Bien Hoa city, a densely populated area with the Dong Nai river system flowing through it. So, how much does pollution directly affect the ecosystem, environment, and human health? The research issue will be clarified through the following two arguments:

- ✓ Argument 1: Dioxin-contaminated soil in the Pacer Iy area, Bien Hoa airbase is neutral sand loam with dioxin residual content in the soil near and exceeding Vietnamese and international standards. In addition, some heavy metals also exist in the soil of this area (Cd, Cr, Cu, Ni, Pb, and Zn). In particular, cadmium remains in the soil at high concentrations, often exceeding the allowable limit of Vietnam and the world.
- ✓ Argument 2: Vetiver grass effectively removes dioxin remaining in the soil over time, especially in the first year of growing grass, with the percentage of dioxin content removed up to 23.4%. At the same time, some heavy metals (Cd, Zn) were removed from this dioxin-contaminated soil in the research area (Pacer Ivy area, Bien Hoa airbase, Dong Nai province).

6. Scientific and practical significance of the thesis

The results of soil characteristics in the Pacer Ivy area, the level of dioxin pollution, and some heavy metals of the soil in the study area before and after planting Vetiver grass. These are the basis for assessing the feasibility of the friendly technology for treating pollutants by plants with large scale. In addition, the results contribute to assessing the economic feasibility of technology using Vetiver grass to treat dioxin and heavy metals.

Treatment technology using plants such as Vetiver grass will save costs in treating residual dioxin after the war. In addition, the results can be used as a basis for local authorities to plan appropriate policies to thoroughly solve the problem of dioxin pollution in the South.

Determining time to achieve the highest treatment efficiency for dioxin in the soil is the basis for establishing a technological process for planting and treating vetiver grass on a large scale for dioxin pollution in the soil environment.

7. New points of the thesis

- Determine the physical and chemical characteristics of dioxin-contaminated soil in the Pacer Ivy area, Bien Hoa airbase.
- Determine the pollution level of some heavy metals in dioxin-contaminated soil at Bien Hoa airbase.
- Determine the effectiveness of Vetiver grass in simultaneously reducing dioxin and heavy metal pollution in the soil. As a result, a technological process for phytoremediation of dioxin-contaminated soil has been proposed at a low cost and environmentally friendly.

Chapter 1. GENERAL

1.1. Natural and social characteristics of the study area

Bien Hoa Airbase (SBBH) is located northwest of Bien Hoa City, Dong Nai province, far from the city. Ho Chi Minh is about 30 kilometers (km) to the northeast. SBBH has as coordinates at $105^0$58'30" North latitude and 106^0 49'10" East longitude, about 700 m far from the west of Dong Nai River. SBBH is an open airbase with a total area of about 1,000 hectares (ha). The ponds and lakes distributed in the airbase become a drainage system when heavy rain occurs. To the south of the Z1 contaminated area, there is a ditch draining rainwater from the airbase into Lake No. 1 and Lake No. 2 and surrounding ponds and vegetable fields, of which Lake No. 1 has an area of about 6,300 m2, lake No. 2 has an area of about 21,000 m2. From Lake No. 2, toxins can follow rainwater through the sewer into Bien Hung 1 and Bien Hung 2 lakes in Trung Dung ward, then follow the drainage system to Dong Nai River; this sewer flows through several residential areas in Buu Long ward. To the southwest of the Z1 infected area, Gate 2 Lake is also located. From Gate 2 Lake, the poison can spread to the fields next to the lake and the fields of Group 29 [8].

The results of previous studies showed that SBBH has very high levels of dioxin contamination in the environment [19] [24]. Bien Hoa Airbase has three large tanks that store herbicides in the airbase, each containing Agent Orange, Agent White, and Agent Green. According to a US military report, SBBH was used to store, process, and transport 98,000 45-gallon (170L) drums of Agent Orange, 45,000 drums of Agent White, and 16,000 drums of Agent Green [33].

1.2. Geological, hydrogeological, topographic, and geomorphological characteristics of the study area

1.2.1. Geological characteristics

Based on the analysis and synthesis results of a series of 1/50,000 maps of the East Ho Chi Minh City newspaper groups, the Vinh An maps, and the Ham Tan - Con Dao maps. In the SBBH airbase, stratigraphic units from old to young exist as follows: Buu Long Formation (T_2abl); Long Binh Formation (J_3lb); Thu Duc Formation (Q^1_{2-3}tđ); Cu Chi Formation (Q^1_3 cc).

1.2.2. Hydrogeological characteristics

Based on the results of the project: "Investigation and preliminary assessment of underground water resources in Bien Hoa city, Dong Nai province" and hydrogeological map of Dong Nai province at 1/25,000 scale [5]. The following aquifer formations exist in the Bien Hoa airport area: Porous aquifers in middle-upper Pleistocene sediments (qp_{2-3}) and Cretaceous fissure aquifer (K1) in the city. Bien Hoa is located in the rocks of the Long Binh Formation (K_1lb). Geological formations could be better in water in the Middle Triassic formation, Buu Long Formation (T_2abl).

According to the results of the assessment of the current status of dioxin pollution at the airbase in 2016 by USAID, the drinking water source taken from wells in and around the airbase did not detect dioxin concentrations exceeding the allowable threshold of the airbase. United States Environmental Protection Agency (USEPA) or Vietnam for drinking water [1]. Groundwater monitoring studies were carried out at Bien Hoa airbase by Dekonta, Czech Republic, in collaboration with the Department of Natural Resources and Environment of Dong Nai province and Office 33. Groundwater monitoring at 7 locations in and around the airbase was conducted. Groundwater sample testing showed that 3/4 of the total wells had low dioxin concentrations [36]. The 2,3,7,8-TCDD content in these wells ranged from 0.18 ppq [pg/L] to 17 ppq. These concentrations are below the USEPA drinking water MCL threshold of 30 ppq for 2,3,7,8-TCDD [38].

1.2.3. Topographic characteristics

SBBH has low terrain, like most districts of the city. Bien Hoa City is adjacent to this airbase. The northern part of the airbase is slightly higher (north to south slope); Nearby areas, such as the Buu Long Tourist Area, have higher elevations than the airbase area. Rainwater/surface water drainage from the Airbase usually flows in the West, South, and Southeast directions, eventually flowing into the Dong Nai River [1].

The terrain of the Pacer Ivy area is relatively flat, with low terrain elevation from East to West, and the pond area has low terrain elevation. Rainwater flows from the Pacer Ivy dioxin-contaminated area into the pond and lower land to the west, then to the Dong Nai River through the sewer system. Therefore, the location of the Pacer Ivy area, the two ponds, and the lowland area near the Ivy area were determined to assess the spread of contaminated soil [20].

1.3. An Overview of dioxin research in the soil environment

1.3.1. an Overview of dioxin

Dioxin is a general term for the group of polychlorinated dibenzo-p-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) with 75 and 135 congeners, respectively (the general chemical structure is shown in Figure 1.6). The term dioxin is also explicitly referred to as 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD), the most toxic substance among cogeners [39].

In the group of dioxins and related compounds (DRCs - Dioxins related compounds), 2,3,7,8-TCDD is the most toxic substance; it is carcinogenic to humans; in addition, it is also the agent that causes a variety of other dangerous diseases, such as melasma, diabetes, myeloma, malignant tumors, peripheral neuropathy and can lead to death [18] [44-45].

1.3.2. Stituation of dioxin pollution in the world and Vietnam

The TEQ content in most exhaust gas samples from industrial waste incinerators in Vietnam is equivalent to or slightly higher than that in developing and newly industrialized Asian countries. However, some exhaust gas samples have unusually high TEQ content (up to 50 ng TEQ/Nm3), showing that the formation and emission of dioxin in Vietnam's incinerators are complex and challenging to control. Incinerator exhaust gas management needs to receive adequate attention and investment. Compared to the TEQ content in emissions in European countries, the level of dioxin emissions in waste incineration activities in our country is much higher. Most analyzed samples have results exceeding the standard threshold of a particular country. Some European countries are 0.1 ng TEQ/Nm3

In Vietnam, the source of dioxin emissions from herbicides, combustion, and industrial activities using high temperatures are still known to be the main processes leading to PCDD/Fs emissions into the environment. The soil environment around factories, plants, and production facilities that use high temperatures, such as incineration of municipal waste, medical waste, metallurgy, and energy, also faces the risk of pollution of dioxins [42].

At Bien Hoa airbase, the pollution situation is very complicated; most of the surface water washing away from the polluted area flows into the Dong Nai River and accumulates in lakes and ponds. Up till now, two isolated landfill sites have collected about 150,000 m^3 of contaminated soil that must be treated, and one area isolates about 10,000 m^2 of heavily polluted soil with a fence. Analysis results compared to the threshold requiring preliminary treatment show that the amount of heavily contaminated soil and sediment that needs to be treated is about over 500,000 m^3. Local people near Bien Hoa airbase face many health risks related to dioxin exposure [55].

1.4. Overview of research on heavy metals in the soil environment

1.4.1. Heavy metals in the soil

Metals in the soil have different origins, including elements originating from bedrock, anthropogenic activities, and soil [56]. Soil environment is the main sink of heavy metals into the environment by anthropogenic activities. Unlike organic pollutants oxidized to carbon(IV) oxide by microbial activity, most metals do not undergo microbial or chemical degradation [59]. Their total concentration in soil persists for a long time after penetration [60]. However, changes in their chemical form (properties) and bioavailability are possible. The presence of toxic metals in soil can severely inhibit the biodegradation of organic pollutants [61].

Heavy metals are not biodegradable; they persist in the environment, can enter the food chain through plants, and eventually accumulate in the human body through biological reactions [62]. The activity of heavy metals in soil and their uptake by plants is influenced by the characteristics of the soil environment, which play an essential role in the bioavailability of heavy metals. The presence of heavy metals in food is a potential threat to human health. Heavy metal exposure from consuming vegetables and foods contaminated with heavy metals is a serious problem, affecting consumer health [65-66].

1.4.2. Sources of heavy metal pollution in Vietnam

Heavy metal pollution from production activities in industrial zones, traditional craft villages, and mining mines is of concern in Vietnam. Research on agricultural soil pollution from toxic trace metals such as arsenic, lead, cadmium, chromium, copper, and zinc has been conducted in Vietnam's industrial zones. The authors have given research results on the distribution of trace metal content for industrial districts in the order Cr> Zn> Pb> Cu> As> Cd [68]. On the other hand, heavy metal pollution has also been evaluated from metal mining areas. Mining activities in Vietnam have resulted in heavy metal pollution, adversely affecting soil quality and posing adverse risks to human health [69].

Previous studies on heavy metals in dioxin-contaminated soil at Bien Hoa airbase showed that the Arsenic content in the dioxin-contaminated area was significantly higher than the national standard [2] [25]. High copper and lead levels were also recorded in some samples [26]. It is recognized that environmental pollution and management risks related to heavy metals, arsenic, dioxin, etc. The cause is not only by the development of the economy, industry, and craft villages, but also by war.

1.5. Remediation of dioxin and heavy metal pollution with plants

1.5.1. Principles of phytoremediation

Phytoremediation is a biological treatment process that uses plants to remove, transform, maintain, extract, or degrade contaminants in soil and Water environments. Plants adopt different mechanisms to grow in metal-contaminated soils without adversely affecting their growth. Some plants remove metals from metabolically active sites by uptake into the roots to translocate the metals to the shoots [72-73].

Phytoremediation efforts have focused on using plants to accelerate the metabolism and degradation of organic pollutants, often associated with microorganisms in the rhizosphere, or to remove dangerous heavy metals from soil or water. Phytoremediation of contaminated sites has the advantages of low cost and minimal impact on the landscape compared to comprehensive remediation strategies involving excavation/removal or stabilization. /in situ chemical conversion [72].

1.5.2. Remediation of persistent organic matter (POP) pollution with plants

Persistent organic pollutants (POPs) in soil have toxic properties and can spread through the food chain, which can be dangerous to humans [78-80]. Plants are used to immobilize, absorb, reduce toxicity, and stabilize or degrade compounds released into the environment from various sources [78-79]. POP pollutants, including PCDD/Fs, PCBs, antibiotics, herbicides, and bisphenol A (BPA), are commonly taken up by plants from the soil through their roots, transported to shoots and leaves, penetrated tissues, or air (through leaves directly from the air or after these pollutants evaporate from the soil) [81].

The organic pollutant's physical and chemical properties, the plant's biological properties, and the environment influence plants' absorption and translocation of organic pollutants. Additionally, the effectiveness of phytoremediation depends on the contact between the contaminant and the plant roots. The root distribution of the plant also determines this treatment efficiency. Plants that are hyperhygroscopic and have short root systems limit the absorption of heavy metals in the top soil layers, thus limiting the contaminant content in the plant [106].

1.5.3. Treatment of heavy metals with plants

Removing metals from soil by growing plants is called phytoextraction. Plants extract metals from the soil and absorb them into the plant, transporting and concentrating them in the above-ground parts. The tree is then harvested and can be safely processed for metal disposal or recycling [68]. A series of processes are involved in heavy metal accumulation in plants, including heavy metal mobilization, root absorption, and transport by xylem from roots to shoots, stems, and leaves [57].

Thus, the absorption and accumulation of heavy metals by plants are more or less related to the origin, mode of appearance, bioavailability of the metal, and physicochemical properties of the soil. The mobility and bioavailability of heavy metals in soil/sediment were evaluated by chemical analysis [111].

Vietnam has implemented several research programs in the last ten years. Studies have identified two species of plants that hyperaccumulate arsenic: native ferns and Pityrogramma calomelanos ferns, and four types of grass suitable for treating lead (Pb) and zinc (Zn), Eleusine indica (L.) Gaertn and Cyperus rotundus L., Cyperaceae, Bermuda grass, and Equisetum arvense, in which E. indica (Indian grass) was found to be a rapid Pb proliferator. These species are native and naturally adapted to habitats contaminated with heavy metals [117].

1.6. Characteristics of Vetiver grass and its application in environmental pollution treatment

Vetiver grass (*Chrysopogon zizanioides*) is native to tropical and subtropical regions of India, Pakistan, Sri Lanka, Bangladesh, and Malaysia. Vetiver grass is known for its pest resistance, pollution tolerance, and ability to grow in harsh soil and climate conditions [118]. Besides, its vast root system, ability to penetrate deep into the soil layer, ability to adsorb metals, and ability to withstand harsh weather conditions make Vetiver grass an excellent choice for biological treatment. Pollutants in soil [118-119].

Accumulation of metals in Vetiver and the transfer of heavy metals from roots to shoots have been noted. Furthermore, Vetiver can absorb and promote the biodegradation of organic substances, so it can be used to treat these pollutants. Vetiver's potential to treat heavy metals and organic waste is superior to other plants.

In 2016, the application of Vetiver grass to treat dioxin pollution was researched [2]. Phytoremediation technology has been tested at Bien Hoa airbase; Vetiver grass has been tested to reduce the toxic chemical dioxin in the soil. Initial results confirm the effectiveness of absorbing dioxin and difficult-to-decompose organic substances. However, Vetiver application in treating dioxin pollution in soil was implemented in Bien Hoa in 2016 with a short sampling time (1 year for three sampling periods). On the other hand, the calculation of processing time is only based on the correlation equation and has yet to reach the final result.

Chapter 2. THEORETICAL BASIC AND METHODS

2.1. Theoretical basis

Synthesis of documents on research results of projects on dioxin and heavy metals in soil at dioxin pollution hot spots as well as the Bien Hoa airbase area over the past 30 years from the first studies at the locations where Agent Orange was stored until the start of the project in 2018. General study on the current status of dioxin contamination in storage areas and areas affected by washing aircraft and Contagion at Bien Hoa airbase. Synthesis of documents on environmental pollution treatment technologies, especially using plants in soil environmental pollution treatment. Technology using plants to treat inorganic and organic pollution.

2.2. Methods

+ Method of referencing and synthesizing documents

+ Survey and sampling methods

+ In-room analysis method

2.3. Data processing methods

Chapter 3. RESULT

3.1. Characteristics of dioxin contaminated soil at Bien Hoa airbase, Dong Nai province

3.1.1. Soil physical and chemical characteristics

The grain composition of the experimental area is dominated by sand content from 54% to 58%, followed by pleasing grain composition (clay, silt) from 36% to 42%, and gravel composition is the least, with an Average content of 4%. The soil in the experimental area is sandy clay loam.

The soil in the study area is neutral, with average pH values of 6.93 and 7.03, respectively, favorable conditions for plant growth.

The Eh value in the soil of the study area in the experimental plot with and without grass is about -33 mV, which is not an optimal condition for plant growth. Another critical parameter of soil quality is soil electrical conductivity (EC). In the study area, the EC value range from 67.50 (µS/cm) to 71.83 (µS/cm) shows that all soil samples have a soil salinity index from very low to low, and The nutritional value of the soil is also meager, creating unsuitable conditions for the growth and development of plants.

The average organic carbon (OC) content in the soil in outdoor experimental plots FT, FC is 0.84% and 0.63%, at deficient levels, and organic matter (OM) in experimental plots grown Grass and non-grass are 1.44% and 1.08%, respectively, showing that the soil structure condition here is deplorable, with shallow structural stability. The soil quality of the study area is neutral sandy clay loam, which is not an optimal environment for crop growth. It has a low soil structure and shallow structural stability and is infertile, arid, impure soil for plants to grow.

3.1.2. The Concentration of dioxin in soil before planting grass

The average dioxin content in the soil in experimental plots planted with grass (FT) and experimental plots without grass were 980±161 (ng TEQ/kg dw) and 2333±737 (ng TEQ/kg dw), respectively. The dioxin content in the soil exceeded the Finnish allowable limit (500 ng TEQ/kg dw).

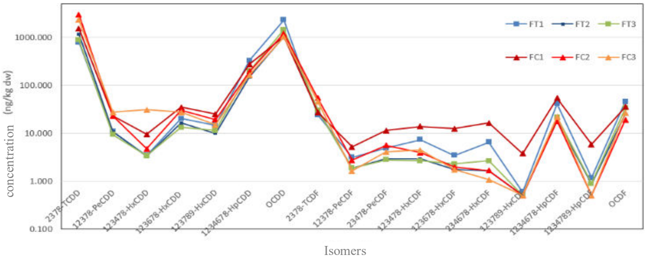
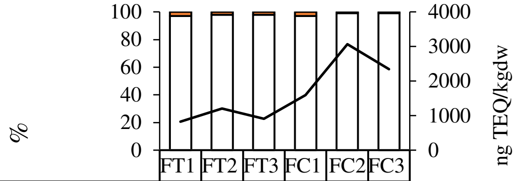


Figure 3.1. Distribution of isomers of dioxin in the soil of the experimental area before planting Vetiver grass.

However, according to the allowable limit for dioxin in the soil in Vietnam and the Netherlands, the dioxin content in grass plots (FT) is less than that for land used for industrial purposes. As for the experimental plot without FC grass, the dioxin content in the soil exceeded the allowable limit. In addition, 2,3,7,8-TCDD is known to be the most toxic substance of dioxin [144]; according to the results of dioxin analysis in soil samples, this substance accounts for 97-99% of the total toxic content of dioxin (Figure 3.2). Dioxin in the soil in the experimental area originates from Agent Orange and is consistent with previous research results.



	FT1	FT2	FT3	FC1	FC2	FC3
Others	3	2	2	3	1	1
2,3,7,8-TCDD	97	98	98	97	99	99
TEQwho	830	1204	907	1592	3065	2342

Figure 3.2. The percentage contribution to WHO-TEQ content of 2,3,7,8- TCDD and other toxic congeners of dioxin.

The soil in the experimental area is a sandy clay loam with poor soil structure strength and a soil environment unsuitable for plant growth. Dioxin residue in the grass growing experimental area with dioxin content varying from 830 - 3065 (ng TEQ/kg dry sample). Dioxin content in the experimental plots planted with grass was lower than in the control plots. The dioxin content in the soil in grass plots is lower than QCVN 45/2012/BTNMT for land used for industrial purposes. Conversely, the dioxin content in the soil in non-grass plots exceeds the limit of the Regulation—this standard.

3.1.3. Heavy metal content in soil before planting grass

Cadmium (Cd) is the most common metal in the study area, with significant differences between FC and FT groups, with average concentrations ranging from 2.28±0.65 mg/kg to 11±6, 73 mg/kg. The observed Cd content in the experimental area is higher than the allowable content of soil types according to EU, WHO (3mg/kg) recommendations and Vietnam (4mg/kg). The content of Chromium (Cr) and Nickel (Ni) in the experimental batch is lower than the allowable level in soil types as recommended by Vietnam (150 mg/kg), EU (180 mg/kg), and WHO (100 mg/kg). Kg). According to EU, WHO, and Vietnam recommendations, Cu and Pb contents measured in FC and FT treatments were lower than the allowable levels. Zinc (Zn) with an average content value of 236±80 mg/kg, and the Zn content in the FT treatment was nearly twice as high as the soil in the FC treatment. Meanwhile, Zn was observed in FC soil with an average value of 117±14 mg/kg. Zn in soil detected during initial sampling was lower than Vietnam, WHO, and EU standards.

Based on the contamination index $\boldsymbol{C_f^i}$, the Cd content in this study showed a very serious level of contamination in both the grass growing treatment (FT) and the control treatment (FC) at the time of the survey before planting. grass. Zn in experimental soil is at a high contamination level (FT) and medium contamination level (FC). For Cr, Ni in the experimental soil showed average contamination levels for both FT and FC treatments. The contamination level of Cu and Pb in the experimental soil shows that the soil is at a high level of contamination (Table 3.1).

The calculated Cd adjustment level for the two grass and non-grass treatments shows that the level of soil contamination before experimenting with the non-grass treatment was very high (Cd=5), and the level of soil contamination before the experiment was very high (Cd=5). The contamination level in the grass-grown treatment was extremely high (Cd=16) (Table 3.1).

Table 3. 1. Contamination index and modify contamination index in the soi in the research area

	Cd	**Pb**	**Cr**	**Ni**	**Cu**	**Zn**	**Outdoor experiment**
Concentration (mg/kg)	11	40	76	25	92	224	FT (Grass)
C_f	83	2	2	1	4	4	
C_d	16						
Concentration (mg/kg)	2,47	35	59	21	57	120	FC (Without grass)
C_f	18	2	2	1	3	2	
C_d	5						

Research results show that the soil at the study site has relatively high levels of heavy metals (Cd, Cu, Pb, and Zn) with the content distribution in the order Cd > Zn >Cu > Cr > Ni > Pb. The heavy metal content values in the soil were higher in the FT treatment than in the FC treatment. According to the assessment of the level of Cd contamination based on the background content of the element Cd in the study area, the soil in the area is contaminated with Cd from very high to extremely high, which will harm the ecosystem and human health in the surrounding area, especially with the normal operations of Bien Hoa airbase.

3.2. Impact of Vetiver on Dioxin contaminated soil characteristics at Bien Hoa airbase, Dong Nai province

3.2.1. The Impact of Vetiver grass on physical and chemical properties of soil

**** The distribution of Particle composition***

The results of grain composition analysis showed that the sand ratio in the second sampling period compared to the first sampling period had slight changes in the grass and non-grass growing treatments. For subsequent sampling periods, the distribution of sand and dust particles fluctuated slightly over time, with a negligible percentage difference of 1-3% (Figure 3.3). This shows that the soil in the study area is stable after more than two years of growing grass.

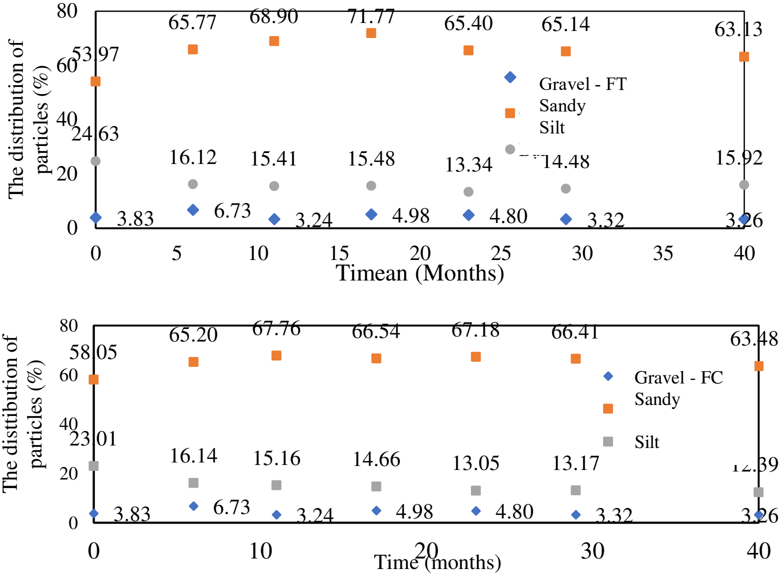


Figure 3.3. Distribution of particles size according to sampling time in the FT grass treatment and the FC non-grass treatment (results from the PEER Project).

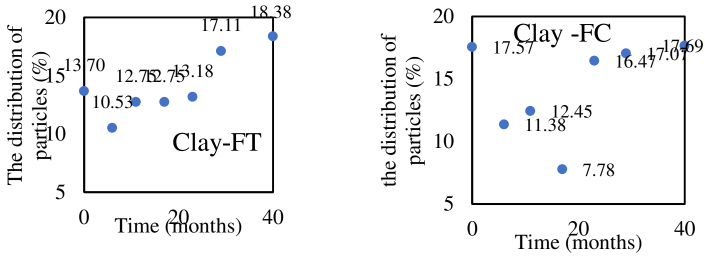


Figure 3.4. The clay distribution in the soil of FT and FC experiments throughout experimental time (results from the PEER Project).

The results of grain composition analysis showed that the sand ratio in the second sampling period compared to the first sampling period had slight changes in the grass and non-grass growing treatments. The sand ratio varied by about 10% in the two treatments and vice versa; the dust ratio also varied by about 10%. For subsequent sampling periods, the distribution of sand and dust particles fluctuated slightly over time, with a negligible percentage difference of 1-3% (Figure 3.4). This shows that the soil in the study area is stable after more than two years of growing grass.

However, when considering the distribution of clay components, the treatments with grass (FT) plants had an increasing proportion of clay over time (Figure 3.4) with a correlation coefficient R^2 = 0.65 and fluctuations in composition. Clay particles in non-grass plots (FC) have a much lower correlation coefficient R2 = 0.12. The impact of Vetiver grass can explain the difference in clay particle composition in the two treatments over time. According to previous studies, the root systems of plants, especially the fine, hairy roots of grass, when penetrating the soil, create significant pressure that binds clay particles and fine particles together. Each other, thus increasing soil structure and soil structural strength [147].

**** Physicochemical properties***

Soil properties were assessed through physicochemical parameters (pH, EC, Eh and OC) and changes over time in the experimental area: pH: The soil environment in the study area was neutral and did not change significantly over time with the grass planting time with pH values over time in the experimental plots with grass and without grass being 7.03 to 6.75 and 6.93 to 6.82, respectively (Figure 3.5).

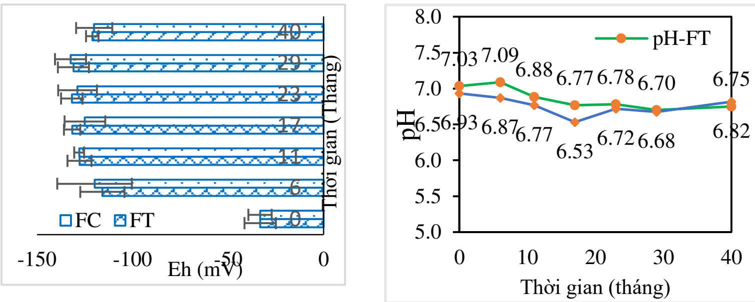


Figure 3.5. Variation of redox potential (Eh) and pH of soil in the experimental area over time (results from the PEER Project).

Redox potential (Eh): The Eh value in the experimental plots tended to increase over time, especially dominant in the grass plot. The Eh value analysis results in the two treatments of grass and no grass were -115 mV to -132 mV and -124 mV to -132 mV, respectively (Figure 3.5). The reducing state of the soil dominant in the grass plot is explained by the ability to pump oxygen through the aerenchyma cells to increase Eh in the root zone of some plant species [152].

EC: For plots planted with grass, EC values range from 127-169 µS/cm, and plots without EC range from 124 to 148 µS/cm, both meeting optimal conditions for plant growth (Figure 3.6). In the grass-planted plot (FT), the EC value tends to increase over time and gradually stabilizes, while the non-grass-planted plot (FC) fluctuates not much and is not different from the initial time. The trend of EC value in the grass treatment was higher than the no-grass treatment due to the development of the surface root system formed from Vetiver grass.

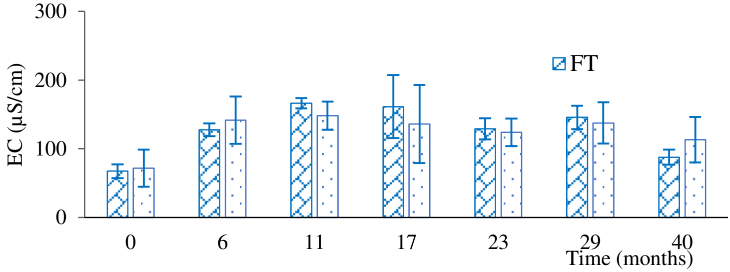


Figure 3.6. The variation of electrical conductivity (EC) in soil over experimental time (results from the PEER Project).

+ OC: OC value does not fluctuate much and tends to be higher in the dry season and lower in the rainy season. OC values ranged from 0.55% (OM = to 1.25% in the experimental plot with grass and from 0.63% (OM = 1.08) to 1.06% in the experimental plot without grass. Ingredients Organic matter in the soil increased over time, showing that soil quality has improved due to vegetation cover [15]. Thus, Vetiver grass is effective in creating humus for the soil, increasing the content of organic matter in the soil, and increasing minerals and soil fertility.

3.2.2. The impaction of Vetiver grass on dioxin content in soil in the study area

**** The fluctuations of dioxin and 2,3,7,8-TCDD concentrations in soil***

Dioxin results from each sampling time showed that the dioxin content in soil samples from the outdoor experimental area in the grass plot gradually decreased over time (40 months) (Figure 3.7). In the beginning, the average concentrations of dioxin and 2,3,7,8-TCDD in the soil samples of the experimental grass plot at the time of the survey were 980±161 (ng TEQ/kg dry soil) and 959±163 (ng/kg dw), respectively. After 40 months of growing Vetiver grass, the average concentrations of dioxin and 2,3,7,8-TCDD were 585±9 (ng TEQ/kg dw) and 568±12 (ng/kg dw), respectively.

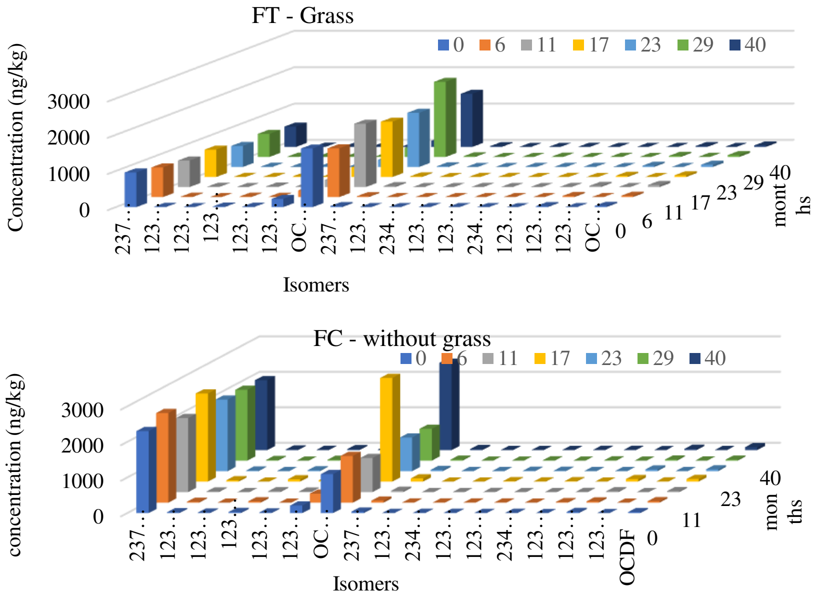


Figure 3.7. The variation of toxic congeners content in soil over time of experiment.

The average concentration of total toxic content of dioxin and 2,3,7,8-TCDD in the soil of experimental plots without grass did not change significantly. Initially, the total toxic concentrations of dioxin and 2,3,7,8-TCDD were 2298±740 ng TEQ/kg dry soil and 2333±737 ng TEQ/kg dry soil, respectively. After 40 months, the concentrations of dioxins in control plots were 1969±885 ng TEQ/kg dry soil and 1998±881 ng TEQ/kg dry soil, respectively.

**** Fluctuations in total toxic content of dioxin and 2,3,7,8-TCDD in roots, shoots, and stems of Vetiver grass***

The results of dioxin analysis in root and shoot samples show that the average dioxin content in root samples at the time of the survey (D0) was 116±15 (ng TEQ/kg dw), which increased. After six months, the strength was 998±669 (ng TEQ/kg dw); after 11 months, it was 700±341 (ng TEQ/kg dw). Most studies have shown that the absorption of organic chemicals from plant roots is passive and a diffusion process [105]. After that, dioxin absorption from the soil into the roots continued to occur but tended to decrease significantly from sampling time D3 to sampling time D6, with the average dioxin content ranging from 469±139 (ng TEQ /kg dw) to 406±48 (ng TEQ/kg dw) (Figure 3.8).

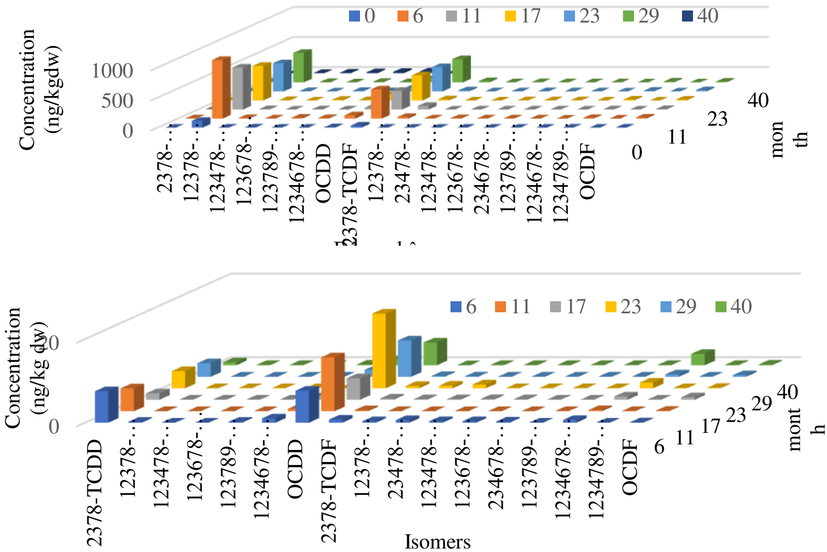


Figure 3.8. The content of toxic congeners of dioxins in roots and shoots in the grass experiment (Data from PEER Project).

The results of dioxin analysis in shoots and roots and fluctuations in dioxin content (Figure 4.6) show that dioxin is transported from roots to shoots. The dioxin content in shoot samples was much lower than in root samples. However, the change in concentration in shoots over each batch of samples was similar to that in root samples. The highest dioxin content in shoot samples analyzed in batches 1 and 2 with average dioxin values of 8.12±2.86 (ngTEQ/kg dry sample) and 5.51±2.83 (ngTEQ/kg), respectively. The total dioxin content transported from roots to shoots is closely related, with a correlation coefficient of $r = 0.55$, $p < 0.05$.

3.2.3. Impact of Vetiver grass on the content of some heavy metals in soil in the study area

The average content of Cadmium in the grass experimental plot decreased over time from 11±6.73 mg/kg (D0) to 6.29±6.06 mg/kg (D6). In contrast, the average Cd content for the treatment without FC grass ranged between 4.28±4.10 mg/kg (D3) and 1.00±0.40 mg/kg (D4). The average Cd content increased from the first to the third sampling time, decreased in the fourth sampling period, and increased in the sixth sampling time.

The average content of zinc in the soil of the experimental area decreased in the grass plot from the first sampling period (D0: 236±80 mg/kg) to the seventh sampling period (D6: 138±66 mg/kg). Thus, the soil's zinc level also decreased throughout the experiment. For the experimental plot without grass (FC), the average zinc content fluctuated slightly, 117±14 mg/kg in sampling periods D0, D1, and D2. It increased slightly in the fourth sampling period, 128±59 mg/kg, and decreased slightly in the following sampling times (D4 and D5), but the difference was not statistically significant ($p>0.05$).

The Pb content in the soil of plots not planted with FC grass and plots planted with FT grass changed over sampling time, but there was no statistical difference between sampling times ($p>0.05$). This means that the impact of Vetiver on Lead content in the soil of the experimental plots needs to be clarified.

Cu content in the FT treatment tended to decrease over time, while the fluctuation in the control group was unclear. In the experimental grass plot, the copper content at the initial time was 89±32 mg/kg, and by the fifth sampling time, the remaining copper content in the soil was 74±45 mg/kg. For the control group, the average copper content at the initial time was 56±13 mg/kg; after 40 months, the average content was 59±30 mg/kg.

The average Cr content in grass-growing treatments ranges from 68 - 81 mg/kg; in non-grass-growing treatments, it is 60 - 74 mg/kg. The average content of Chromium (Cr) in the soil of the experimental area did not tend to decrease. However, it fluctuated slightly over time in both treatments ($p>0.05$), which means that Vetiver grass is ineffective in reducing Cr content in the soil.

Similar to Cr, the average nickel (Ni) content in the experimental area's soil is lower than the allowable limit and fluctuates slightly over time. The average Ni content in the FT grass treatment ranged from 23 - 29 mg/kg, while that in the non-grass (FC) treatment ranged from 33 to 49 mg/kg but did not differ. Statistically, this also means that Vetiver grass does not affect the Ni content in the soil.

3.2.4. Effective treatment of dioxin and some heavy metals in soil by Vetiver grass in the study area

A portion of the contaminant can be removed from the soil through treatment, while the remaining portion of the contaminant is usually measured to calculate the removal rate with the following formula [167]:

Removal rate (%) = $(1 - A/B) \times 100$ (4)

In which: A is the remaining portion of the pollutant after treatment;

B is the total amount of pollutants before treatment;

4.4.1. Effective dioxin treatment of Vetiver grass in dioxin-contaminated soil

Vetiver grass is effective in treating dioxin pollution as well as 2,3,7,8-TCDD in the soil of the experimental area (Figure 3.9). The content of dioxin and toxic congeners 2,3,7,8 -TCDD in both grass and non-grass treatments tended to decrease over time, with a faster decrease rate and a more profound decrease in the planted treatment.

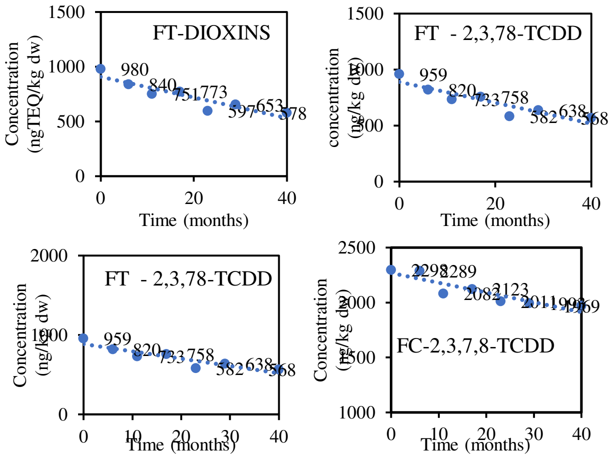


Figure 3.9. Changes in 2,3,7,8-TCDD content and total dioxins content.

The dioxin content in the soil in the experimental plot without grass (FC) changed due to dioxin being washed away by rain or photochemical processes occurring [168]. The change in dioxin content in soil in plot FC was also affected by rainfall $r^2 = -0.976$, $p<0.01$.

Bảng 3.2. Percentage of dioxin removal in dioxin-contaminated soil by Vetiver grass

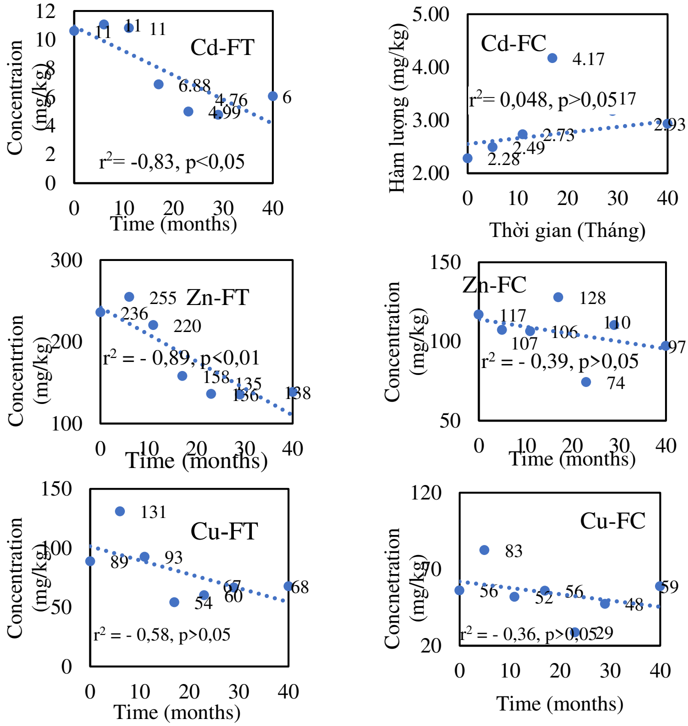
Sampling time	Time	TEQ$_{who}$ (ng TEQ/kg dw)	2,3,7,8-TCDD (ng/kg dw)	Effective content reduction (%)	
				TEQ$_{who}$	2,3,7,8-TCDD
D0	10/2018	980±161	959±163	0	0
D1	4/2019	840±156	820±158	14.5	14.5
D2	10/2019	751±3	733±5	23.4	23.5
D3	5/2020	773±32	758±31	21.2	21.0
D4	10/2020	598±36	582±38	39.0	39.3
D5	4/2021	653±55	638±54	33.4	33.5

D6	3/2022	585±9	568±12	40	41

Vetiver grass can effectively reduce dioxin pollution in the soil in the Pacer Ivy area, Bien Hoa military airbase. The amount of dioxin in the soil of the experimental area was removed by about 41% (Table 4.1) after 40 months of research in the grass plot according to calculations based on formula (4). The effectiveness of Vetiver grass in removing dioxin in soil is best in the first 12 months of growing grass and then gradually slows down.

**** Effective treatment of Vetiver grass for dioxin-contaminated soil***

The concentration of Cd and Zn reduced significantly because of Vetiver grass throughout the experimental time, but other metals have not happened.



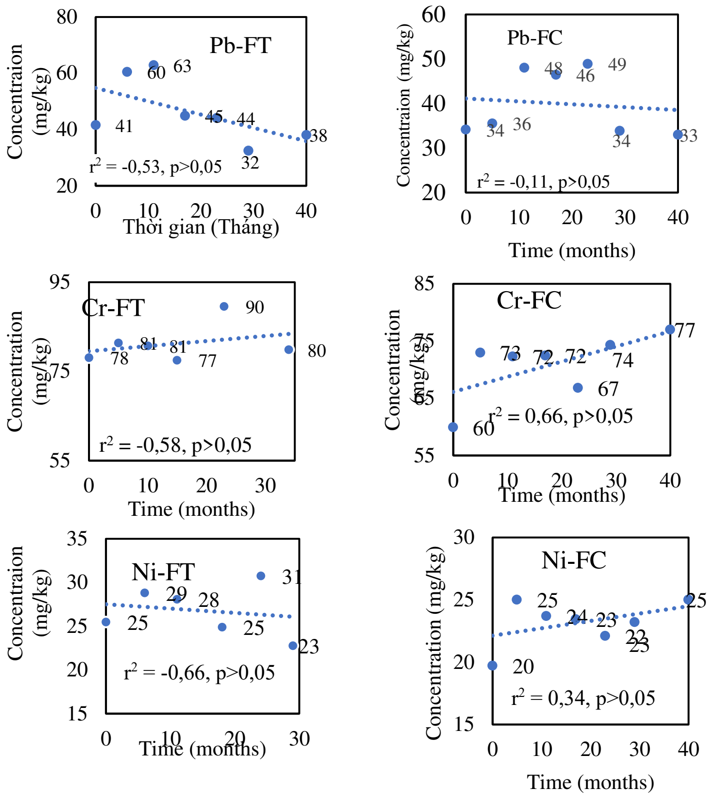


Figure 3.10. The variation content of heavy metals throughout time experiments

Thus, Vetiver grass only has the effect of removing Cadmium and Zinc in the soil in the FT treatment. Comparing data collected at the FC cell over sampling times, the total trace metal content fluctuates over time, but not much and not statistically significant (Figure 3.10).

The form of heavy metal in the soil can explain why Vetiver grass impacts changes in heavy metal content. The ionic form of Cd and Zn mainly appears in the form of exchangeable ions easily absorbed by plants [173]. For this reason, cadmium and zinc levels have been significantly reduced thanks to Vetiver. For Pb and Cu, the percentage of metallic phase existence in the reduced form is higher (up to 41% for Cu and 59% for Pb). It also means that Pb and Cu are mobile and bioavailable. However, Pb will only be mobile under suboxic conditions [174].

Furthermore, Ni (80-89%) and Cr (84-90%) can be considered almost immobile due to the high percentage of these elements in the residue (surrounding the mineral). These metals are firmly bound to minerals, and the resistant component metals in the F4 phase have relatively high stability and low bioavailability [174]. One possible explanation is that Vetiver does not absorb the levels of both metals.

After 40 months of growing grass, the content of heavy metals decreased sharply after one year of growing grass (Table 3.3). The concentration of needles decreased sharply starting from the second sampling period D2, with Cd content decreasing by 43% and Zn content decreasing by 41% in the soil during the study time.

Table 3.3. The percentage of heavy metals in the soil was remediated by Vetiver grass

Time	**Time for collecting a sample**	**Cadmium mg/kg**	**Zinc mg/kg**	**Effective rediamation (%)**	
				Cadmium	Zinc
D0	10/2018	11±6.73	236 ± 80	0	0
D1	5/2019	11 ± 5.48	255 ± 89	0	-8
D2	10/2019	11 ± 7.14	220 ± 73	0	7
D3	5/2020	6.72 ± 4.10	158 ± 46	44	37
D4	10/2020	4.99 ± 2.51	136 ± 26	55	46
D5	4/2021	4.76 ± 2.12	135 ± 9	57	43
D6	3/2022	6.29 ±6.06	138±66	43	41

Analysis of soil samples, shoots, roots, and stems in the experimental area growing Vetiver grass during the 40-month research period showed that Vetiver grass effectively removed dioxins and some heavy metals in the soil (Cd and Zn). As for dioxin, compared to the initial time, the dioxin content has decreased by 41% after 40 months of growing grass. For heavy metals, Vetiver most effectively removed Cd (43%), followed by zinc (41%) after 40 months.

3.2.5. The growth process of Vetiver grass and the technological process of treating dioxin and other pollution in soil with Vetiver grass

**** The growth process of Vetiver grass:*** Monitoring data shows that after 7 to 8 months of grass planting, the grass begins to flower, and the flowering time lasts about three months. After 11 months of planting, the grass reaches a maximum height of about 2.2 m. It is the best growing period for Vetiver grass. After 10 to 15 months, the grass begins to age, and dry stems appear; this is the degeneration stage and the natural biological cycle of this grass variety in other everyday soil environments. After the third sampling period (November 2019), the grass was cut short to 25-30cm height to promote growth. However, the growth rate of grass height in the following years is less than the first year (Figure 4.15).

At the time of solid grass growth, the average dioxin concentration in roots was 998±669 (ng TEQ/kg dry sample) and 714±341 (ng TEQ/kg dry sample), corresponding to the dioxin content in shoots of 8. 12±2.16 (ng TEQ/kg dry sample) and 5.51±2.83 (ng TEQ/kg dry sample), this is also the time when grass grows best. This shows that grass growth directly affects the absorption of pollutants [100].

**** The technological process of treating dioxin and other pollution in soil with Vetiver grass***: The technological process of treating dioxin and other pollution in the soil by using Vetiver grass is built based on biological characteristics, methods, knowledge of growing and caring for Vetiver grass shown in three steps:

+ Step 1: Determine the level of pollution in the soil

+ Step 2: Treat soil contaminated with dioxin and other pollution

+ Step 3: Treat grass after harvest

CONCLUSION

Based on the analysis and evaluation of research results on physical and chemical characteristics of soil, dioxin content, and some heavy metals in the experimental area at Pacer Ivy area, Bien Hoa military airbase, Dong Nai, the essay The judgment draws some conclusions as follows:

1. The soil distributed in the study area is neutral clay sand with poor soil structure, arid, and low in nutrients, so it is unsuitable for plant growth. However, Vetiver grass can grow and develop well in this soil. It improves soil properties, specifically changing the soil structure, increasing humus, and promoting the composting process. Decompose organic matter from microorganisms in the rhizosphere, create minerals, and increase soil fertility.

2. The soil in the experimental area is contaminated with dioxins and some heavy metals such as Cd, Cr, Cu, Ni, Pb, and Zn. The total dioxin content in the soil is near the allowable threshold for soils used for industrial purposes for grass-grown experimental plots. It exceeds this threshold for non-grass-grown plots (QCVN 45). For metals, the content of Cd and Zn in the grass-growing treatment exceeded the allowable limit, and other elements were within the limit according to QCVN 03/MT/2023-BTNMT.

3. Vetiver grass effectively removes dioxin and some heavy metals (Cd, Zn) in the soil. The growth and development of the grass directly affects the efficiency of pollution treatment. The best treatment efficiency is when the grass reaches its highest growth, which is from 10-15 months of planting.