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Phytoremediation of Contaminated Land Using Vetiver (*Chrysopogon zizanioides* L.) in Bangladesh Perspective

Dr. Mohammad Shariful Islam
Professor, Department of Civil Engineering
Bangladesh University of Engineering and Technology (BUET)
Dhaka-1000, Bangladesh
Email: msharifulbd@gmail.com

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Outline of the Presentation

01

Background and Problem Statement

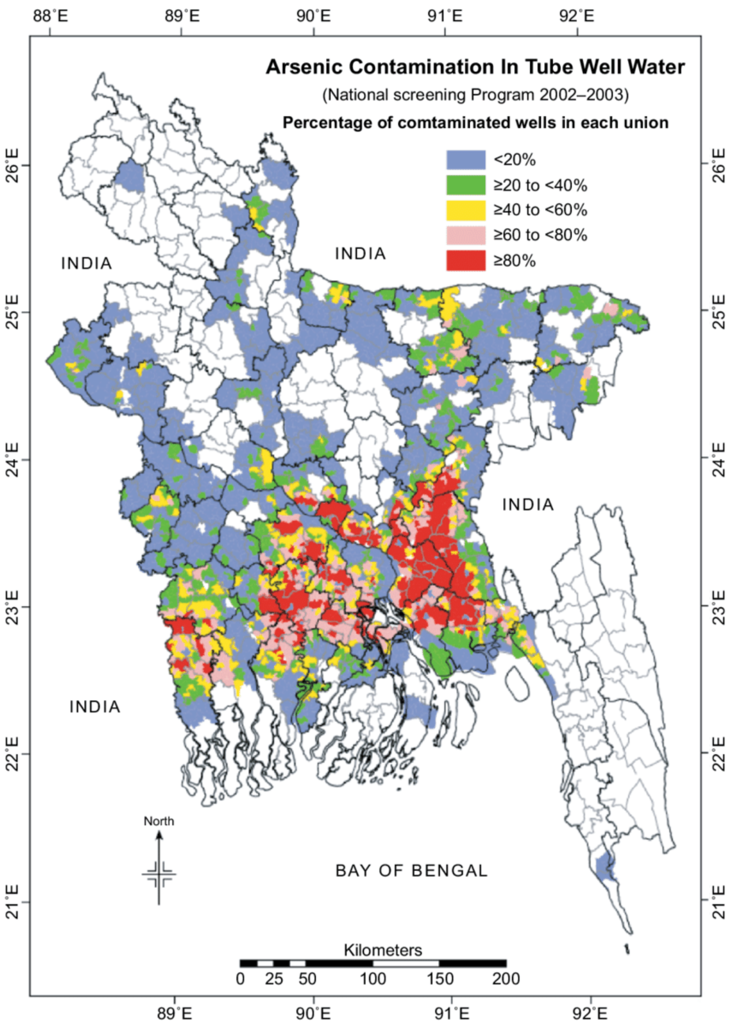
Extent of Soil Pollution in Bangladesh

Soil health in Bangladesh is deteriorating due to human activities and environmental factors, such as the excessive and unregulated use of chemical fertilizers, rising salinity, deforestation, industrial pollution, the use of topsoil in brick kilns, and the improper disposal of diverse wastes, including household, industrial, electronic, and medical, contributing to the presence of harmful heavy metals in the soil.

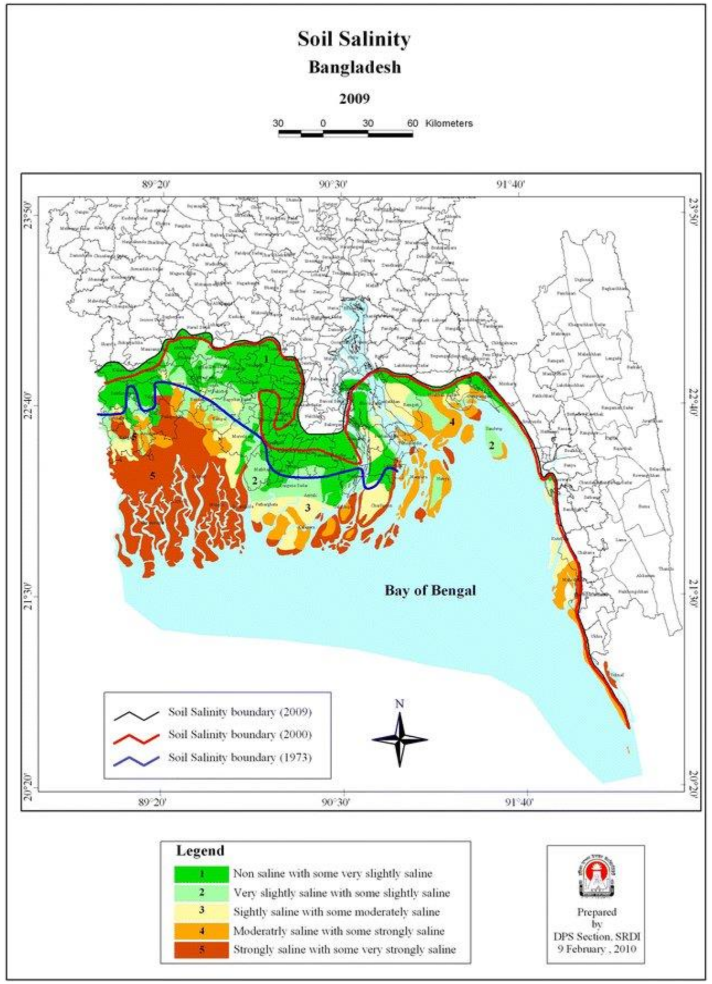
Following soil pollution problems are severe:

i) **Heavy Metal:** Heavy metals like As, Cd, Cr, Hg, Pb, Cu, Zn, Ni are common pollutants in the soil environment that are biologically toxic.

ii) **Salinity:** Salinity in soil can reduce plant growth and water quality resulting in lower crop yields and water availability.



BAMWSP (2005)



SRDI (2010)

Soil Contamination State in Asia

Area	Name of Country(ies)	Type of Pollutant
South Asia	Bangladesh, India, Pakistan, Nepal, Sri Lanka	Arsenic, cadmium, chromium (VI), copper, lead, mercury, nickel and zinc
East Asia	Mainland China, Taiwan Province of China	Trace element, e.g., arsenic, cadmium, chromium, copper, lead, mercury, nickel, zinc and DDT, PAHs and HCHs (hexachlorocyclohexanes)
	Republic of Korea	Oil, trace elements, e.g., arsenic, cadmium, chromium (VI), copper, mercury and lead, PCDD/Fs, fluorine
	Japan	Radionuclide pollutant
Southeast Asia	Brunei Darussalam, Cambodia, Indonesia, Malaysia, Myanmar, The Philippines, Singapore, Thailand and Viet Nam	Arsenic, cyanide, lead, oil, TCE, PCE, iron

FAO and UNEP (2021)

Food and Agriculture Organization of the United Nations

SUSTAINABLE DEVELOPMENT GOALS

Soils and SDGs

Healthy soils perform/provide key functions and ecosystem services

GLOBAL SOIL PARTNERSHIP

https://www.fao.org/3/cb8303en/cb8303en.pdf

Direct Contribution

Indirect Contribution

How Soil Pollution Hinders SDGs?

1 NO POVERTY
Soil pollution reduces income for rural people

2 ZERO HUNGER
Soil pollution affects food security

3 GOOD HEALTH AND WELL-BEING
Soil pollution affects the global mortality

5 GENDER EQUALITY
Women working in vulnerable jobs are more exposed to soil pollution

6 CLEAN WATER AND SANITATION
Soil pollution causes water pollution

7 AFFORDABLE AND CLEAN ENERGY
Fossil fuels are a major source of contaminants

8 DECENT WORK AND ECONOMIC GROWTH
Poorly managed stockpiles can cause pollution

10 REDUCED INEQUALITIES
Soil pollution disproportionately affects people

11 SUSTAINABLE CITIES AND COMMUNITIES
Transport and waste production causes soil pollution

12 RESPONSIBLE CONSUMPTION AND PRODUCTION
Industrial activities and mining are sources of soil pollution

13 CLIMATE ACTION
Soil pollution contributes climate change

14 LIFE BELOW WATER
Marine pollution is caused by erosion of polluted soils

15 LIFE ON LAND
Contaminants in soil are pass into the food chain

16 PEACE, JUSTICE AND STRONG INSTITUTIONS
Ethnic minority groups are affected by soil pollution

17 PARTNERSHIPS FOR THE GOALS
Developed countries need to actively collaborate on this issue

FAO and UNEP (2021)

Permissible Limits of Heavy Metals in Soil and Plants

Sl No	Elements	[α]Target Values of Soil (mg/kg)	[β]Intervention Values of Soil (mg/kg)	[γ]Permissible Value of Plants (mg/kg)
1	Cd (Cadmium)	0.8	12	0.02
2	Cr (Chromium)	100	360	1.3
3	Cu (Copper)	36	190	10
4	Pb (Lead)	85	530	2
5	Ni (Nickel)	35	210	10

[α]Target values are specified to indicate desirable maximum levels of elements in unpolluted soils, Denneman and Robberse (**1990**)
[β]Intervention when remedial action is necessary, Denneman and Robberse (**1990**)
[γ]WHO (**1996**), Osmani et al. (**2015**)

Permissible Limits of Heavy Metals in Soil and Plants

Elements	βIntervention Values of Soil (mg/kg)	Triggered levels for human health (mg/kg)	ψNot Polluted (mg/kg)	ψHeavily Polluted (mg/kg)	ξTRV in Soil for Terrestrial Plant (mg/kg)	ξTRV in Soil for Soil Invertebrate (mg/kg)	ϒPermissible Value of Plants (mg/kg)	λRegulatory limit (mg/kg)
Cr (Chromium)	360	200	<25	>75	1.8^{δ}	2^{δ}	1.3	100
Cu (Coper)	190	500	<25	>50	10	32	10	600
Pb (Lead)	530	500	<40	>60	46	100	2.00	600
Zn (Zinc)	-	2000	<90	>200	9	199	0.60	1500
Cd (Cadmium)	12	40	-	>6	2	10	0.02	100

βIntervention when remedial action is necessary, Denneman and Robberse (**1990**)
ψEPA guidelines for sediments, Ogbeibu et al. (**2014**)
ξScreening Level Ecological Risk Assessment Protocol, Appendix E: Toxicity Reference Values, U.S. EPA, August **1999**.
http://www.epa.gov/osw/hazard/tsd/td/combust/eco-risk/volume3/appx-e.pdf
δConcentration value corresponds to hexavalent chromium only
λNJDEP (**1996**)
ϒWHO (**1996**)

Land Degradation and Erosion

https://www.climateaction.org/news/land-degradation

https://youmatter.world/

Land degradation could threaten 700 million people globally

- **Erosion**
- **Contamination**
- Salinization
- Deforestation
- Urbanization

Climate, soil, **vegetation cover**, topography, human and animal activity influence the Erosion. It has both environmental and economic impacts.

02

Ways of Solving the Problem

Methods of Remediation

Based on the location of treatment, there are two categories of soil remediation techniques, ex-situ and in-situ.

1. **Ex-situ:** Ex-situ technique involves treatment of contaminated soil after removing it from the site.
2. **In-situ:** In-situ methods aim to remediate the soil without need for excavation.

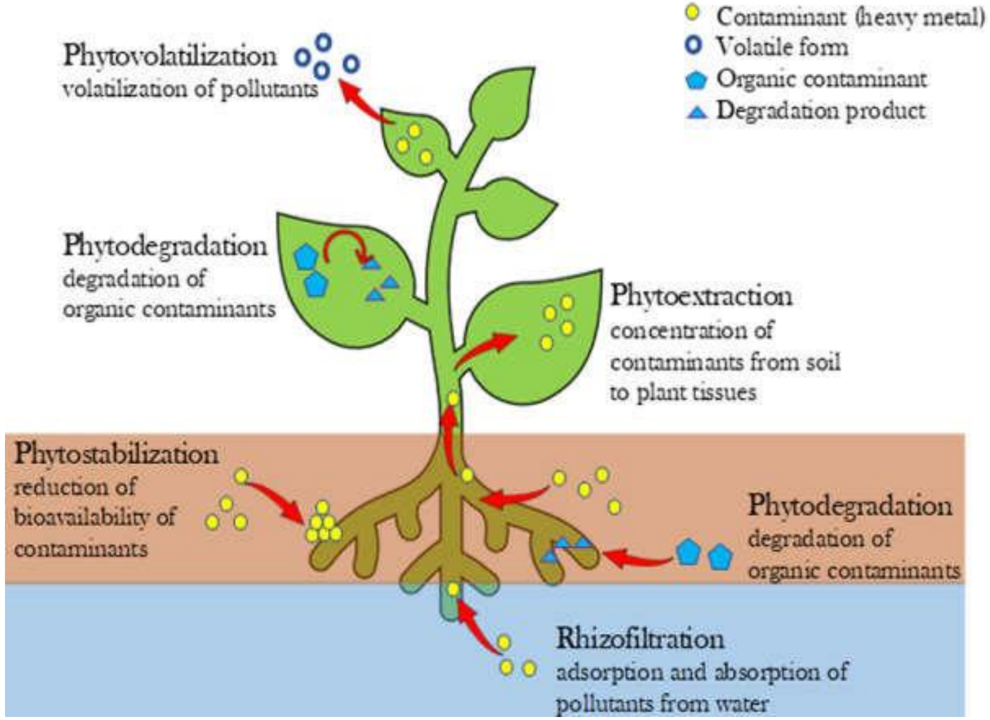
Some common methods of soil remediation include:

- **Microbial Bioremediation:** Uses microorganisms, plants, or their enzymes
- **Cleanup of Contaminated Soil:** Excavates and transports contaminated soil to secure landfills
- **Immobilization of Inorganic Contaminants:** Uses efficient amendments for contaminant immobilization
- **Soil Washing:** Separates contaminated fines but doesn't destroy contaminants
- **Phytoremediation:** Uses green plants, especially metallophytes, to remove heavy metals from contaminated soils through natural or chelate-assisted modes that use agents like EDTA to increase bioavailability

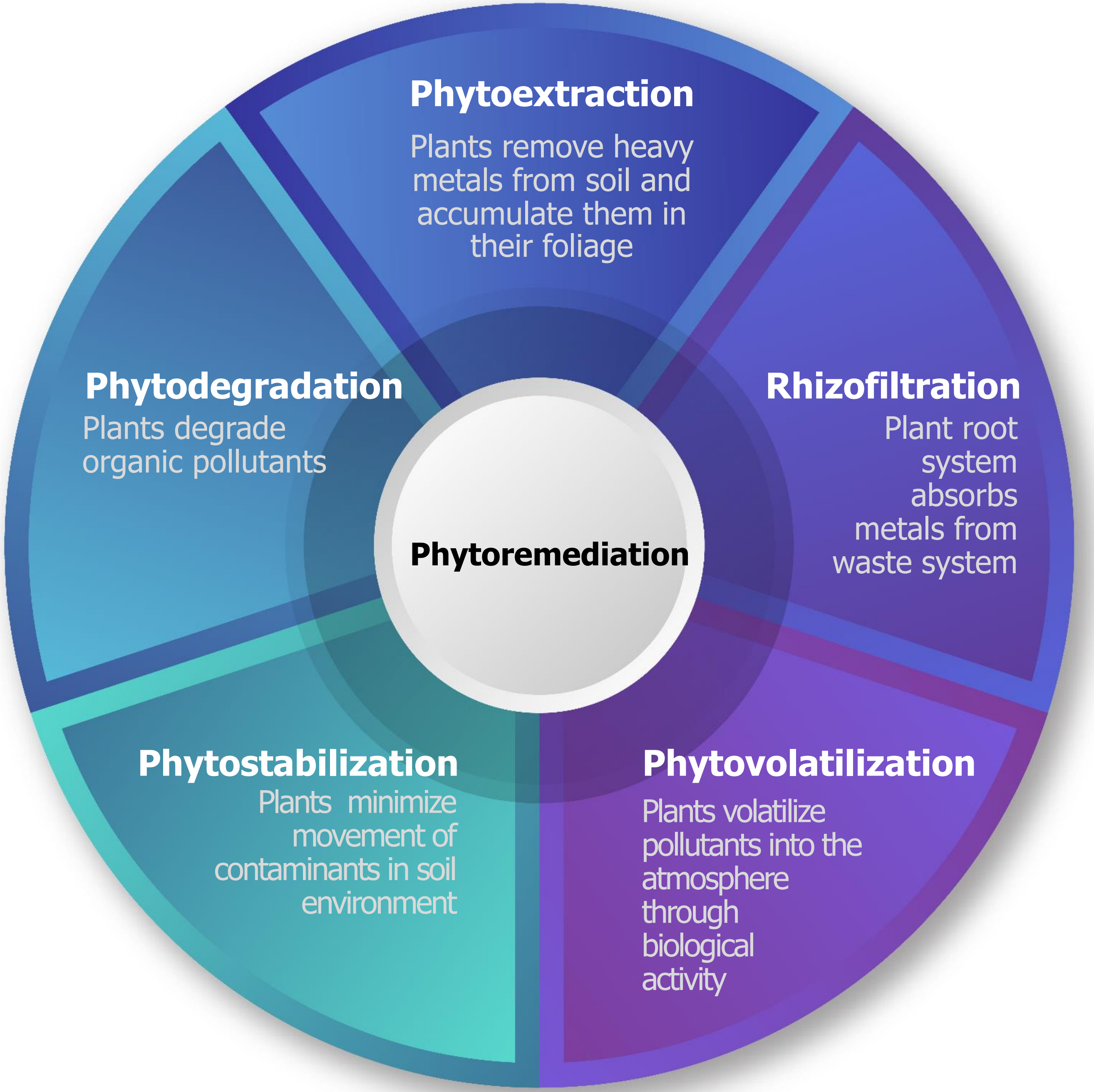
The physico-chemical and phytoremediation techniques can remediate heavy metal contamination but physico-chemical methods are costlier and create environmental issues.

Phytoremediation

Types of Phytoremediation



Rigoletto et al. (2020)



Phytoremediation

Limitations of Phytoremediation

- **Long time** is required for clean-up.
- Efficiency is usually limited by the **slow growth rate and low biomass**.
- Difficulty in the mobilization of more tightly bound fractions of metal ions from soil
- It is applicable to sites with low to moderate levels of metal contamination because plant growth is not sustained in heavily polluted soils.
- There is a **risk of food chain contamination** in case of mismanagement and lack of proper care.

Recommendations

- Advancement in spectroscopic and chromatographic techniques should be exploited to improve understanding of the fate of metal ions in plant tissues, which in turn will improve understanding of metal hyperaccumulation and tolerance in plants.
- Existing plant diversity should be explored for hyperaccumulation of various heavy metals to find new effective metal hyperaccumulators.

Plant Species for Phytoremediation

Cadmium (Cd)

Plant Name	Plant Species	Chelating Agents (dose in mM)	Root Concertation (mg/kg)	Shoot Concentration (mg/kg)	References
Indian Mustard	*Brassica juncea L.*	EDTA (2.5)	500.00	-	Blaylock et al., 1997
White Clover	*Trifolium repens*	EDTA (5.0)	3.27	-	Kos et al., 2003
Empress Tree	*Paulownia tomentosa*	EDTA (10.0)	0.57	-	Doumett et al., 2008
Empress Tree	*Paulownia tomentosa*	TAR (10.0)	0.47	-	Doumett et al., 2008
Empress Tree	*Paulownia tomentosa*	GLU (10.0)	0.53	-	Doumett et al., 2008

EDTA=Ethylene Diamine Tetra Acetic Acid, TAR= Tartrate, GLU= Glutamate

Chromium (Cr)

Plant Name	Plant Species	Chelating Agents (dose in mM)	Root Concertation (mg/kg)	Shoot Concentration (mg/kg)	References
Vetiver	*Vetiveria zizanioides*	EDTA (5.0)	19.70	1.6	Choudhury et al., 2016
Indian Mustard	*Brassica juncea L.*	-	61.55	30.0	Choudhury et al., 2016
French Marigold	*Tagetes patula*	-	13.00	21.9	Choudhury et al., 2016
Napier Grass	*Pennisetum purpureum*	-	452.10	1241.6	Juel et al., 2021

Plant Species for Phytoremediation

Copper (Cu)

Plant Name	Plant species	Chelating Agents (dose in mM)	Root Concertation (mg/kg)	Shoot Concentration (mg/kg)	References
Vetiver	*Vetiveria zizanioides*	EDTA (5.0)	13.90	29.00	Choudhury et al., 2016
Indian Mustard	*Brassica juncea L.*	-	9.75	41.85	Choudhury et al., 2016
French Marigold	*Tagetes patula*	-	21.90	13.00	Choudhury et al., 2016
Common Bean	*Phaseolus vulgaris*	EDTA (5.0)	625.00	-	Luo et al., 2005
Corn Plant	*Zea mais*	EDTA (5.0)	428.00	-	Luo et al., 2005
Empress Tree	*Paulownia tomentosa*	EDTA (10.0)	45.50	-	Doumett et al., 2008
Empress Tree	*Paulownia tomentosa*	TAR (10.0)	36.80	-	Doumett et al., 2008
Empress Tree	*Paulownia tomentosa*	GLU (10.0)	46.60	-	Doumett et al., 2008
Sunflower	*Helianthus annuus*	EDTA (5.0)	480.00	105.00	Yeh et al., 2015
Chinese cabbage	*Brassica campestris*	EDTA (5.0)	420.00	150.00	Yeh et al., 2015
Cattail	*Typha latifolia*	EDTA (5.0)	330.00	115.00	Yeh et al., 2015
Reed	*Phragmites communis*	EDTA (5.0)	275.00	135.00	Yeh et al., 2015

EDTA=Ethylene Diamine Tetra Acetic Acid, TAR= Tartrate, GLU= Glutamate

Plant Species for Phytoremediation

Lead (Pd)

Plant Name	Plant species	Chelating Agents (dose in mM)	Root Concertation (mg/kg)	Shoot Concentration (mg/kg)	References
Vetiver	*Vetiveria zizanioides*	EDTA (5.0)	19.40	33.90	Choudhury et al., 2016
Indian Mustard	*Brassica juncea L.*	-	6.00	16.50	Choudhury et al., 2016
French Marigold	*Tagetes patula*	-	37.65	36.25	Choudhury et al., 2016
Indian Mustard	*Brassica juncea*	EDTA (2.5)	3580.00	-	Blaylock et al., 1997
Rapeseed Plant	*Brassica napus*	EDTA (5.0)	93.92	-	Kos et al., 2003
Empress Tree	*Paulownia tomentosa*	EDTA (10.0)	31.00	-	Doumett et al., 2008
Empress Tree	*Paulownia tomentosa*	TAR (10.0)	12.40	-	Doumett et al., 2008
Empress Tree	*Paulownia tomentosa*	GLU (10.0)	16.20	-	Doumett et al., 2008

EDTA=Ethylene Diamine Tetra Acetic Acid, TAR= Tartrate, GLU= Glutamate

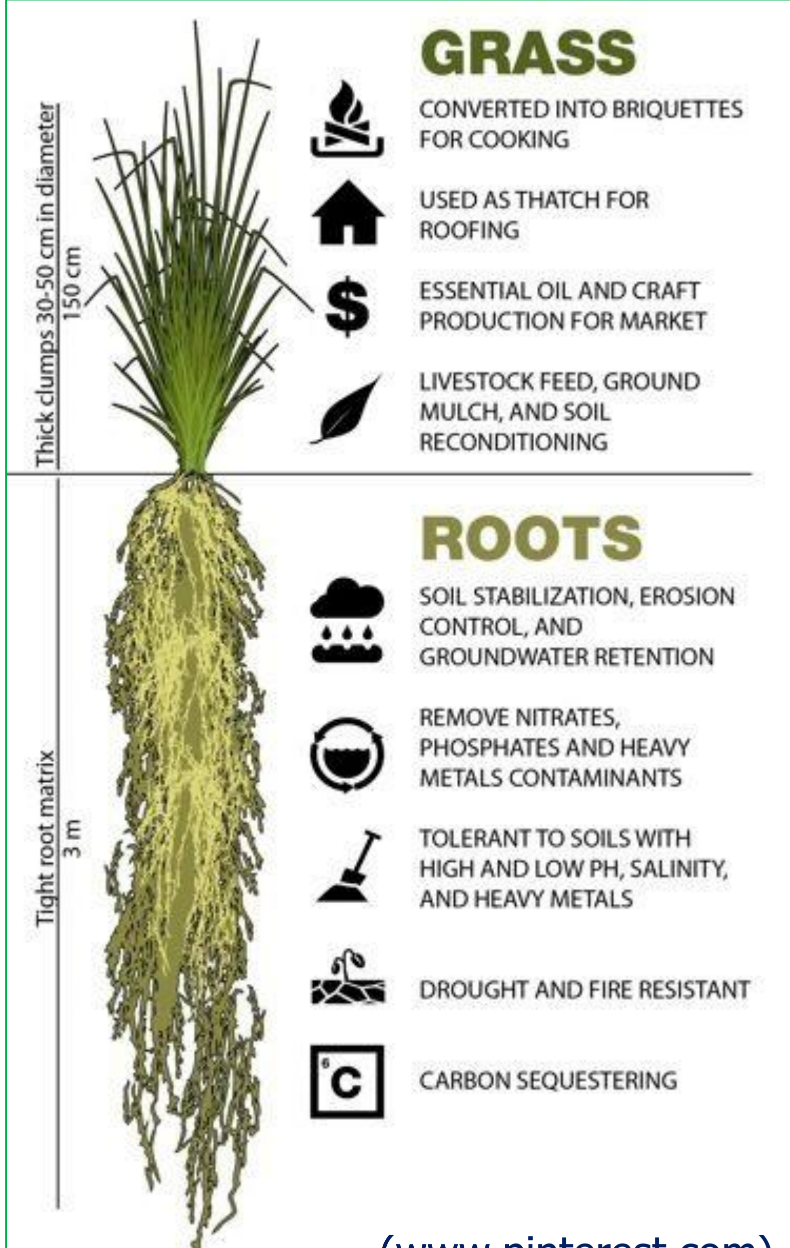
Plant Species for Phytoremediation

Zinc (Zn)

Plant Name	Plant Species	Chelating Agents (dose in mM)	Root Concertation (mg/kg)	Shoot Concentration (mg/kg)	References
Vetiver Plant	*Vetiveria zizanioides*	EDTA (5.0)	1130.00	995.00	Choudhury et al., 2016
Indian Mustard	*Brassica juncea L.*	-	584.50	562.00	Choudhury et al., 2016
French Marigold	*Tagetes patula*	-	265.15	159.05	Choudhury et al., 2016
Indian Mustard	*Brassica juncea*	EDTA (2.5)	1080.00	-	Blaylock et al., 1997
White Clover	*Trifolium repens*	EDTA (5.0)	168.00	-	Kos et al., 2003
Empress Tree	*Paulownia tomentosa*	EDTA (10.0)	149.00	-	Doumett et al., 2008
Empress Tree	*Paulownia tomentosa*	TAR (10.0)	104.00	-	Doumett et al., 2008
Empress Tree	*Paulownia tomentosa*	GLU (10.0)	114.00	-	Doumett et al., 2008
Sunflower	*Helianthus annuus*	EDTA (5.0)	6700.00	3380.00	Yeh et al., 2015
Chinese Cabbage	*Brassica campestris*	EDTA (5.0)	5200.00	2650.00	Yeh et al., 2015
Cattail	*Typha latifolia*	EDTA (5.0)	3450.00	1900.00	Yeh et al., 2015
Reed	*Phragmites communis*	EDTA (5.0)	2600.00	1780.00	Yeh et al., 2015

EDTA=Ethylene Diamine Tetra Acetic Acid, TAR= Tartrate, GLU= Glutamate

Vetiver Grass



(www.pinterest.com)

Factors		Tolerance Limit
pH		3.0 to 10.5
Salinity		10 to 47.5 dS/m
Sodicity		up to 48% ESP
Temperature		−15°C to 55°C
Drought		up to 6 months
Submergence		3 to 4 months
Heavy Metal		(in mg/kg)
-	Arsenic	100–250
-	Cadmium	20–60
-	Copper	50–100
-	Chromium	200–600
-	Lead	>1 500
-	Mercury	>6
-	Nickel	100
-	Selenium	>74
-	Zinc	>750
Rainfall/Precipitation		250-5000 mm

Characteristics	Value
Tensile Strength of Root	75 MPa
Carbon Sequestration Capacity	15-150 ton C/ha/year

www.vetiver.org (Ziyuan Feng)

Carbon Sequestration of Vetiver and Other Grasses

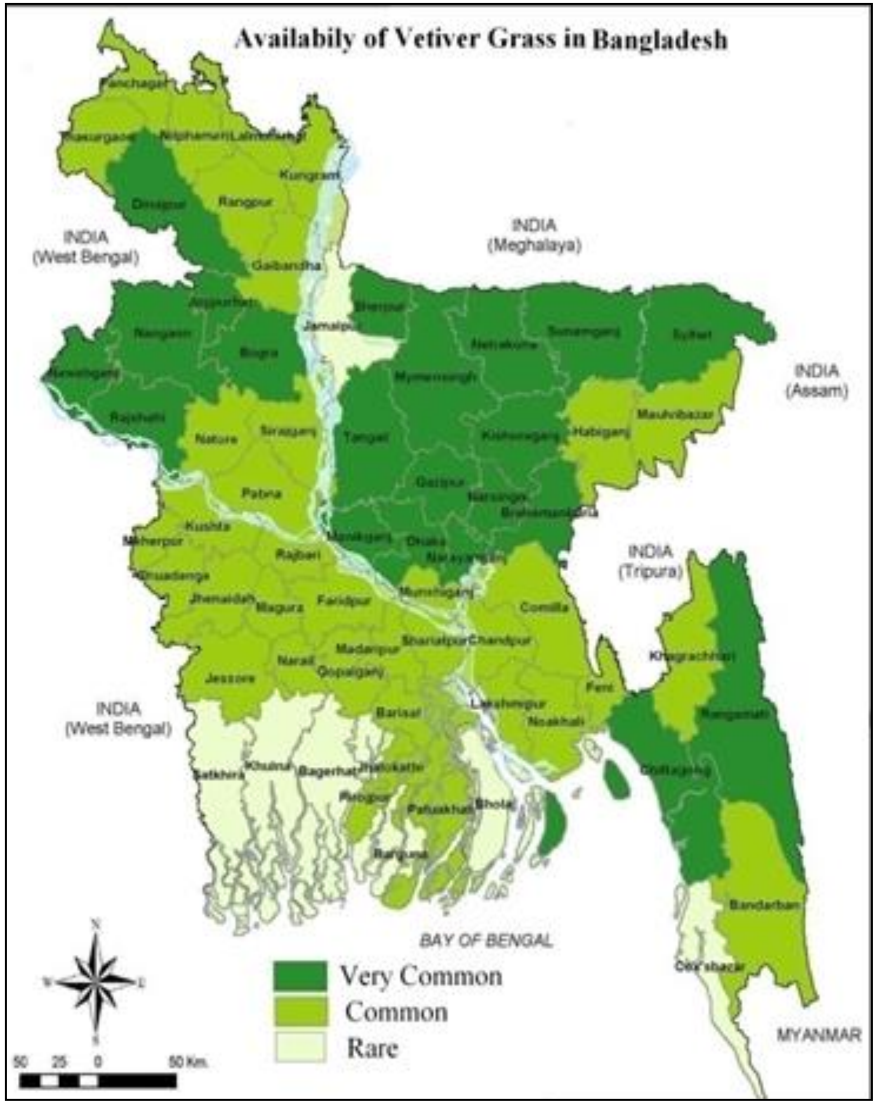
Sl. No.	Type of Grass	Sequestered Carbon	Reference
1	Vetiver (*Chrysopogon zizanioides*)	15.24 ton C/ha/year	Singh et al. (2014), Lakshmi and Sekhar (2020)
2	Lemongrass (*Cymbopogon citratus*)	5.38 ton C/ha/year	
3	Palmarosa (*Cymbopogon martini*)	6.14 ton C/ha/year	
4	Hybrid Napier	49.42 ton C/ha	Toppo et al. (2021)
5	Sudan Grass (*Sorghum × drummondii*)	42.36 ton C/ha	
6	Zoysiagrass (*Zoysia japonica*)	5.54± 0.21 ton C/ha/year	Hamido et al. (2016)
7	Bermuda Grass (*Cynodon dactylon*)	2.09± 0.1 ton C/ha/year	
8	Centipedegrass (*Eremochloa ophiuroides*)	4.23± 0.14 ton C/ha/year	
9	Turfgrasses	0.32-0.78 ton C/ha/year	Qian et al. (2010)
10	Deep rooted tropical grasses in South America	100-500 ton C/ha/year	Grimshaw (n.d.)
11	Vetiver (*Chrysopogon zizanioides*)	150 ton C/ha/year	
12	Vetiver (*Chrysopogon zizanioides*)	0.2 kg C/plant/year	www.vetiver.org

Carbon Sequestration: is the process of preventing CO_2 from entering the Earth's atmosphere;
Carbon Sink: the reservoirs that retain the CO_2.

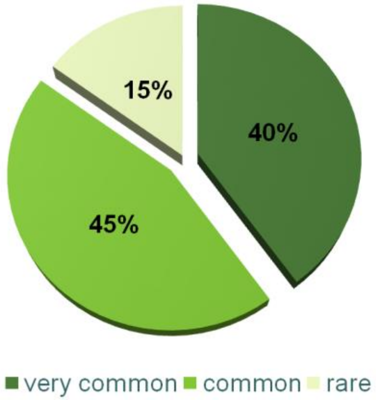
As a whole, it can be said that vetiver can sequester higher carbon than other common grasses. However, the reporting and the data varies significantly in the existing literature which emphasize the need for further research on this topic considering soil characteristics, geographical locations.

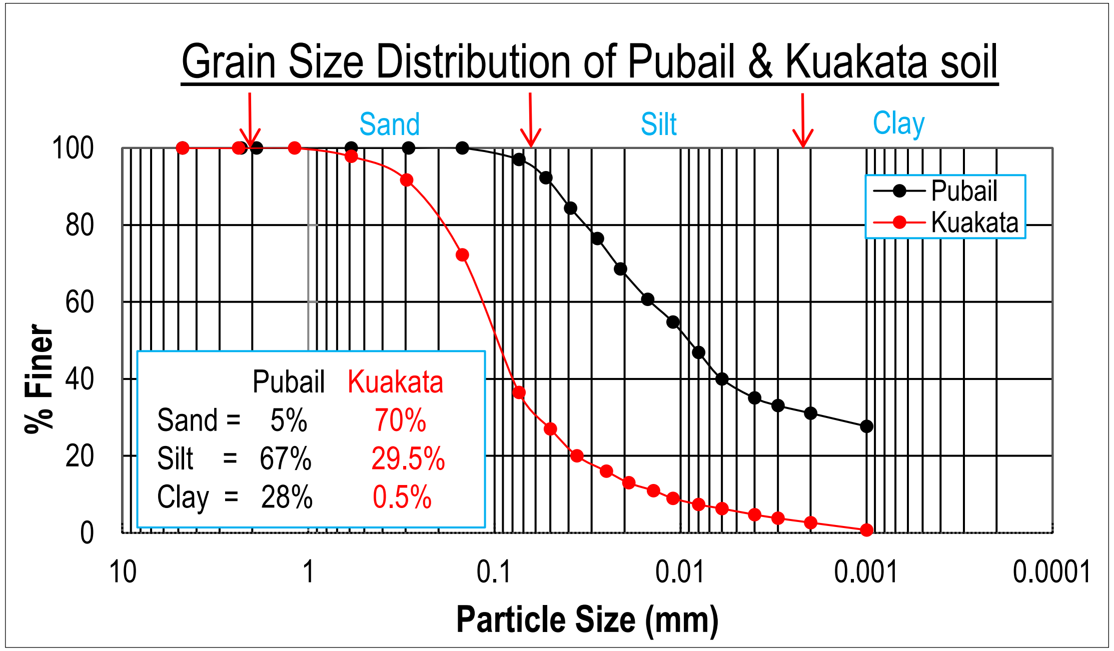
Commercial Uses of Vetiver

Native Habitats of Vetiver in Bangladesh



Thomas et al., 2002





Phytoremediation Mechanism of Vetiver

Reference	Contaminant	Additives	Suitability	
			Phytoextraction	Phytostabilization
Wilde et al., 2005	Pb	EDTA		✓
Minh and Khoa, 2009	Pb	-	✓	
Minh and Khoa, 2009	Cd	-		✓
Datta et al., 2010	As	-	✓	
Roongtanakiat and Sanoh, 2011	Zn	-	✓	
Abaga et al., 2014	Cd	-	✓	
Saeb et al., 2015	CN	-	✓	
Vargas et al., 2016	Zn	Humic acid		✓
Vargas et al., 2016	Cu	Humic acid	✓	
Attinti et al., 2017	Pb	EDDS	✓	
Ng et al., 2019	Cd,Pb,Cu,Zn	EDTA	✓	
Mu et al., 2019	Pb, Cr, Cu, and Zn	CaO-activated silicon-based slag		✓
Mu et al., 2019	Cd	CaO-activated silicon-based slag	✓	
Chintani et al., 2021	Cr	-		
Chintani et al., 2021	Ni	-	✓	
Kriti et al., 2021	Ni, Cd	-		✓
Bahraminia et al., 2015	Pb	Mycorrhizal Fungi		✓
Huong et al., 2022	Dioxin	-		✓

Threshold Level of Heavy Metals for Vetiver

Heavy Metals	Threshold Levels in Soil (mg/kg)	Threshold Levels in Plants (mg/kg)
Arsenic	100-250	21-72
Cadmium	20-60	45-48
Copper	50-100	13-15
Chromium	200-600	5-18
Lead	>1500	>78
Mercury	>6	>0.12
Nickel	100	347
Selenium	>74	>11
Zinc	>750	880

03

Research and Development

Phytoremediation Studies in Bangladesh

Reference	Location	Soil Type	Targeted Contaminants	Vegetation for Phytoremediation	Findings
Rahman et al., 2007	Manikganj	Paddy field	As	*S. polyrhiza L.*	Arsenate-exposed S. polyrhiza accumulated 79% more arsenic than DMAA-exposed
Mahmud et al., 2008	Khulna, Satkhira, Bagerhat, Brahmanbaria	-	As	*Dryopteris filix-mas, Blumea lacera, Mikania cordata, Ageratum conyzoides, Clerodendrum trichotomum, Ricinus communis*	As-tolerant accumulators, suitable for phytoextraction purpose
Islam et al., 2010	Chapai Nabwabganj	-	As	*Pteris vittata L.*	Tailoring solutions to local environments is key
Ye et al., 2011	Nonaghata, Faridpur and Sonargaon	Paddy field	As	*Pteris vittata*	The arsenic content in rice grains was reduced by 50-58%
Mayda et al., 2013	Savar	-	As	*Adiantum sp, Microlepia sp, Pteris vittata, Christella sp*	*Pteris vittata* excels in uptaking soil arsenic, tolerating 4000ppm concentration

Phytoremediation Studies in Bangladesh

Reference	Location	Soil Type	Targeted Contaminants	Vegetation for Phytoremediation	Findings
Choudhury et al., 2016	Buriganga	Riverbed Sediment	Cu, Cr, Pb, Zn	*Indian Mustard (Brassica juncea) and French Marigold (Tagetes patula)*	Marigold excels in uptake of Cr, Pb, and Cu, while Indian mustard is efficient in Zn uptake
Islam et al., 2016	Munshiganj	Agriculture Land topsoil	As	*Vetiver Grass (Vetiveria zizanioides)*	Vetiver grass can lower soil arsenic by up to 23%.
Uddin, 2016	Bhaluka Upazila	Industrially polluted soil	Pb	*Corchorus capsularis L., Hibiscus cannabinus, (Hibiscus sabdariffa L.)*	Jute CVE-3 showed the highest Pb concentration (108.12 mg/kg), while kenaf HC-95 had the lowest (80.28 mg/kg) in post-harvest soil.
Islam et al., 2018	Kallyanpur	Reclaimed land soil	NH_3, NO_3, NO_2, PO_4, COD, pH	*Vetiver Grass (Vetiveria zizanioides)*	Soil organic matter increased from 4.3% to 6.4%, with 96% and 95% removal of ammonia and phosphate from wastewater
Rahman et al., 2019	Sitakunda Coast	Sediment	Fe, Ti, Zr, Rb, Zn, Sr, Pb, Y, Cu, Cr, As	*A. alba and A. ilicifolius*	Bioconcentration factors were <1, but transfer factors were >1 for most heavy metals in both plant species

Phytoremediation Studies in Bangladesh

Reference	Location	Soil Type	Targeted Contaminants	Vegetation for Phytoremediation	Findings
Hasan et al., 2021	Savar	Soil around tanning Industries	Cr	Eichhornia crassipes, Xanthium strumarium L., *Cynodon dactylon*, Croton bonplandianum Baill	*Xanthium strumarium* L. showed high TF and BCF values for Cr
Riza and Hoque, 2021	Kaliakair	Soil around textile industries	Cu and Zn	Bryophyllum pinnatum	Bryophyllum pinnatum is a promising hyperaccumulator plant with BCF>1 and TF>1 values, suitable for phytoextraction
Juel et al., 2021	Gazipur	Soil containing tannery sludge	Cr, Cu, Zn, Pb	Napier Grass, Indian Mustard	Fast-growing Napier grass, can accumulate more heavy metals than Indian mustard over its lifespan
Present Study	Buriganga	Riverbank Soil	Cu, Cr, Pb, Ni, Zn	Vetiver Grass (*Vetiveria zizanioides*)	EDTA absorption efficiency did not improve above 1-2 mmol/kg of soil, and greater values induced leaf discoloration

Vetiver-based Phytoremediation Studies around the World

Arsenic, As

Reference	Location	Soil	Sampling Depth (cm)	Harvesting Period (Days)	Amend-ments	Results					
						Before	After	Vetiver Uptake	Removal Efficiency	BCF	TF
Srisatit et al., 2003	Bangkok, Thailand	Silt Loam	×	90	×	50-150 mg/kg	×	×	0.04-0.05%	×	×
Datta et al., 2010	Texas, Florida, USA	×	×	120	×	45-450 mg/kg	×	×	0.60-10.6%	×	×
Hosamane, 2012	Karnataka, India	×	×	60	×	10-50 mg/kg	×		63-85%	×	×
Oshunsanya et al., 2012	Nigeria	Dumpsite	0-100	90	×	10.5 mg/kg	×	0.03 mg/kg	×	×	×
Caporale et al., 2014	Rutgers, USA	Sandy Loam	Pot Depth 30	120	Arbuscular Mycorrhizal Fungi	12.5-50 mg/kg	×	×	×	×	<1
Islam et al., 2016	Munshiganj, Bangladesh	Sand	×	180	×	18.8 mg/kg	15.2-16.6 mg/kg	×	×	×	×
Singh et al., 2017	Mumbai, India	×	×	14	×	10-200 µM	×	×	×	×	<1

Vetiver-based Phytoremediation Studies around the World

Cadmium, Cd

Reference	Location	Soil	Sampling Depth (cm)	Harvesting Period (Days)	Amend-ments	Results					
						Before	After	Vetiver Uptake	Removal Efficiency	BCF	TF
Roongtanakiat and Chairoj, 2001	Thailand	Sandy Soil	×	120	15-15-15 Fertilizer	1.02-4.08 mg/kg	×	×	×	×	<1
Zhuang et al., 2007	Lechang, China	Pb/Zn Mine Soil	×	107	N:P:K (1:1:1) Fertilizer, EDTA	7.2 mg/kg	×	13.7 mg/kg	×	0.53	
Sampanpanish et al., 2008	Tak Province, Thailand	Clay Loam	0-30	120	15-15-15 NPK	46.24 mg/kg	×	×	×	×	>1
Minh and Khoa, 2009	Danag, Vietnam	Sand, Clay	×	90	×	0-60 mg/kg	×	2.95 mg/kg (shoot)	×	×	<1
Roongtanakiat and Sanoh, 2011	Phetchaburi, Thailand	Sandy Loam	×	120	×	14-6462 mg/kg	×	×	×	×	<1

Vetiver-based Phytoremediation Studies around the World

Cadmium, Cd (Continued)

Reference	Location	Soil	Sampling Depth (cm)	Harvesting Period (Days)	Amend-ments	Results					
						Before	After	Vetiver Uptake	Removal Efficiency	BCF	TF
Oshunsanya et al., 2012	Nigeria	Dumpsite	0-100	90	×	4.5 mg/kg	3.03 mg/kg	×	75-82%	×	>1
Abaga et al., 2014	Burkina Faso	Lixisol and Vertisol	0-20	180	×	2-10 mg/kg	×	21.8 mg/kg	×	2.3 & 22	0.38 & 7.3
Kriti et al., 2021	Delhi, India	Ni-Cd Battary Waste Cont Soil	×	120	Compost	30-120 g electrolyte waste	1156.1 mg/g	×	×	×	<1
Benavides et al., 2021	Pennsylvania, USA	Silt Loam	0-20	×	×	0.2-0.7 mg/kg	×	×	×	>1	×

Vetiver-based Phytoremediation Studies around the World

Chromium, Cr

Reference	Location	Soil	Sampling Depth (cm)	Harvesting Period (Days)	Amend-ments	Results					
						Before	After	Vetiver Uptake	Removal Efficiency	BCF	TF
Pillai et al., 2013	Kerala, India	Sandy Loam	×	60	Organic Manure	50-200 mg/kg	×	×	85-92.25%	×	×
Vijayan and Sushama, 2017	Kerala, India	Dump yard	×	365	×	115.67 mg/kg	49.6 mg/kg	×	×	3.21	1.1
Chintani et al., 2021	West Java, Indonesia	×	×	28	Urea, NPK	50-300 mg/kg	×	167.8 mg/kg	×	0.06-0.75	0.24-7.710

Vetiver-based Phytoremediation Studies around the World

Copper, Cu

Reference	Location	Soil	Sampling Depth (cm)	Harvesting Period (Days)	Amend-ments	Results					
						Before	After	Vetiver Uptake	Removal Efficiency	BCF	TF
Roongtanakiat and Chairoj, 2001	Thailand	Sand	×	120	15-15-15 Fertilizer	26.83-107.32 mg/kg	×	×	×	×	×
Sampanpanish et al., 2008	Tak Province, Thailand	Clay Loam	0-30	120	15-15-15 NPK	25.89 mg/kg	26.00 mg/kg	×	×	×	×
Liu et al., 2009	Nanjing, China	Wasteland near Cu mine Area	×	60	Urea (1.5 g/kg soil) and KNO3 (1.587 g/kg soil)	0.95-173.08 mg/kg	×	×	×	×	<1
Abaga et al., 2014	Burkina Faso	Lixisol and Vertisol	0-20	180	×	100-500 mg/kg	×	4635 mg/kg	×	1.6 and 16	0.07 and 2.60
Vargas et al., 2016	El Cuadron La Union, Spain	Sandy Loam	0-20	365	Humic Acid	146 mg/kg & 6617 mg/kg	×	×	×	×	0.13-0.70

Vetiver-based Phytoremediation Studies around the World

Lead, Pb

Reference	Location	Soil	Sampling Depth (cm)	Harvesting Period (Days)	Amend-ments	Results					
						Before	After	Vetiver Uptake	Removal Efficiency	BCF	TF
Roongtanakiat and Chairoj, 2001	Thailand	Sand	×	120	15-15-15 Fertilizer	23.98-95.92 mg/kg	×	×	×	×	×
Chantachon et al., 2004	Mahasarakham, Thailand	×	0-30	84	×	22 mg/kg	×		×	×	<1
Wilde et al., 2005	Savannah, USA		0-100	120	EDTA, NPA Fertilizer	300-4500 ppm/kg	×	1390-1450 ppm/kg	×	×	<1
Zhuang et al., 2007	Lechang, China	Pb/Zn Mine Soil	×	107	N:P:K (1:1:1) Fertilizer, EDTA	119 mg/kg	×	155 mg/kg	×	0.01	×
Sampanpanish et al., 2008	Tak Province, Thailand	Clay Loam	0-30	120	15-15-15 NPK	87.96 mg/kg	28 mg/kg		×	×	×
Minh and Khoa, 2009	Danag, Vietnam	Sand, Clay	×	90	×	0-700 mg/kg	×	74.65 mg/kg (shoot)	×	×	<1
Wu et al., 2010	Shaogua, China	×	×	120	AMF and Refuse Compost	107 mg/kg	×	0.56-1.04 mg/seedlings	×	×	<1
Roongtanakiat and Sanoh, 2011	Phetchaburi, Thailand	Sandy Loam	×	120	×	14-6462 mg/kg	×	×	×	×	<1

Vetiver-based Phytoremediation Studies around the World

Lead, Pb (Continued)

Reference	Location	Soil	Sampling Depth (cm)	Harvesting Period (Days)	Amend-ments	Results					
						Before	After	Vetiver Uptake	Removal Efficiency	BCF	TF
Andra et al., 2011	Texas and Baltimore, USA	×	×	70	EDTA, EDDS	<1500 mg/kg	×	×	×	×	<1
Oshunsanya et al., 2012	Oyo, Nigeria	Dumpsite	0-100	90	×	16.0 mg/kg	4.5 mg/kg	×	80-82.22%	×	<1
Bahraminia et al., 2015	Shiraz, Iran	Sandy Clay Loam	0-30	120	AMF Fungi	50-800 mg/kg	×	×	×	×	<1
Attinti et al., 2017	Texas, USA	Loam	0-15	300	EDDS	1000-2400 mg/kg	×	×	×	×	<1
Vijayan and Sushama, 2017	Kerala, India	Dump-yard Soil	×	365	×	82.24 mg/kg	93.88 mg/kg	×	×	0.35	0.5

Vetiver-based Phytoremediation Studies around the World

Nickel, Ni

Reference	Location	Soil	Sampling Depth (cm)	Harvesting Period (Days)	Amend-ments	Results					
						Before	After	Vetiver Uptake	Removal Efficiency	BCF	TF
Vijayan and Sushama, 2017	Kerala, India	Dump yard	×	365	×	35.54 mg/kg	32.62 mg/kg	×	×	2.10	0.60
Chintani et al., 2021	West Java, Indonesia	×	×	28	Urea, NPK	50-300 mg/kg	×	66.30 mg/kg	×	0.07-1.84	0.90-10.78
Kriti et al., 2021	Delhi, India	Ni-Cd Battery Waste Cont. Soil	×	120	Compost	30-120 g electrolyte waste	699.00 mg/kg	×	×	×	<1

Vetiver-based Phytoremediation Studies around the World

Zinc, Zn

Reference	Location	Soil	Sampling Depth (cm)	Harvesting Period (Days)	Amend-ments	Results					
						Before	After	Vetiver Uptake	Removal Efficiency	BCF	TF
Zhuang et al., 2007	Lechang, China	Pb/Zn Mine Soil	×	107	N:P:K (1:1:1) Fertilizer, EDTA	93 mg/kg	×	269 mg/kg	×	0.06	×
Sampanpanish et al., 2008	Thailand	Clay Loam	0-30	120	15-15-15 NPK	2124.26 mg/kg	90 mg/kg		×	×	×
Roongtanakiat et al., 2009	Tak Province, Thailand	×	0-15	120	EDTA and DTPA	814 mg/kg & 5039 mg/kg	×	4.54-12.39 mg/pot	×	×	0.764
Wu et al., 2010	Shaogua, China	×	×	120	AMF and Refuse Compost	107 mg/kg	×	2.36-3.70 mg/seedlings	×	×	<1
Roongtanakiat and Sanoh, 2011	Phetchaburi, Thailand	Sandy Loam	×	120	×	14-6462 mg/kg	×	×	×	×	<1
Vargas et al., 2016	El Cuadron La Union, Spain	Sandy Loam	0-20	365	Humic Acid	146 mg/kg & 6617 mg/kg	×	×	×	×	0.056 - 0.125

Vetiver-based Phytoremediation Studies in Bangladesh

Location	Soil Type (Based on Source)	Targeted Contaminants	Vegetation for Phytoremediation	Reference
Buriganga	Riverbank Soil	Cu, Cr, Pb, Ni, Zn	Vetiver Grass (*Vetiveria zizanioides*)	Choudhury et al. (n.d.), Parshi (2015), Dey (2016)
Buriganga	Riverbed Sediment	Cu, Cr, Pb, Zn	Indian Mustard (*Brassica juncea*) and French Marigold (*Tagetes patula*)	Choudhury et al. (2016), Ahmad (2015)
Munshiganj	Agriculture Land topsoil	As	Vetiver Grass (*Vetiveria zizanioides*)	Islam et al. (2016)
Kallyanpur	Reclaimed Land	NH_3, NO_3, NO_2, PO_4, COD, pH	Vetiver Grass (*Vetiveria zizanioides*)	Islam et al. (2018)

Phytoremediation of Buriganga Riverbank Soil

Background

The Buriganga river, crucial to numerous economic activities in Dhaka, is experiencing severe soil quality degradation due to unrestrained wastewater discharge from various riverside industries, despite the immense economic value and reuse potential of brownfields, particularly from relocated tannery industries.

Objectives

1) To compare the growth of vetiver grass in heavy metal-contaminated Buriganga riverbank soil to that in normal garden soil and investigate the effects of the synthetic and organic chelating agent on the growth rate of vetiver.
2) To assess heavy metal uptake by vetiver grass from the contaminated Buriganga riverbank soil under different chelate dosing conditions.

Contaminated Buriganga River Water

Study Location

Experimental Methods

Location

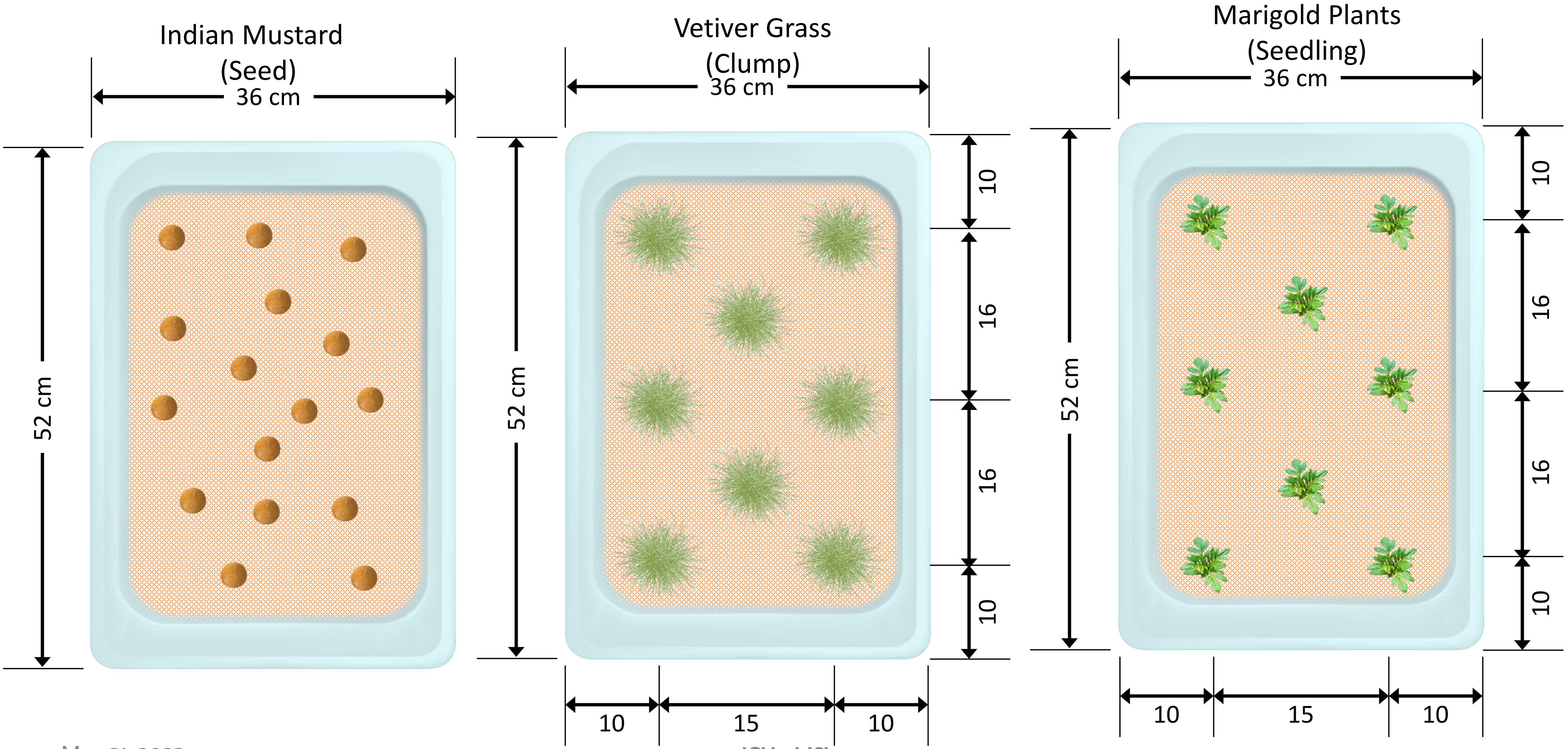
Bank of Buriganga River

Soil Property

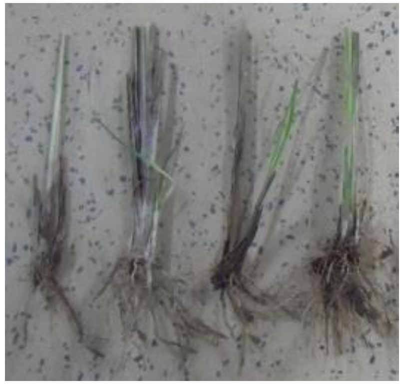
Four Soil Samples were analyzed: (i) Sand, (ii) Organic Clay-1, (iii) Mixed Soil (Sand & Clay), **(iv) Organic Clay-2**

Sample	Specific gravity	LL(%)	PL (%)	PI (%)	OC (%)	Sand (%)	Silt (%)	Clay (%)
Buriganga Riverbank	2.62	47	22	25	2.0	13.0	75.0	10.0
Garden Soil	2.70	37	28	9	1.3	16.2	58	6.2

Experimental Methods



Experimental Methods



VG Planation

VG, Week 4

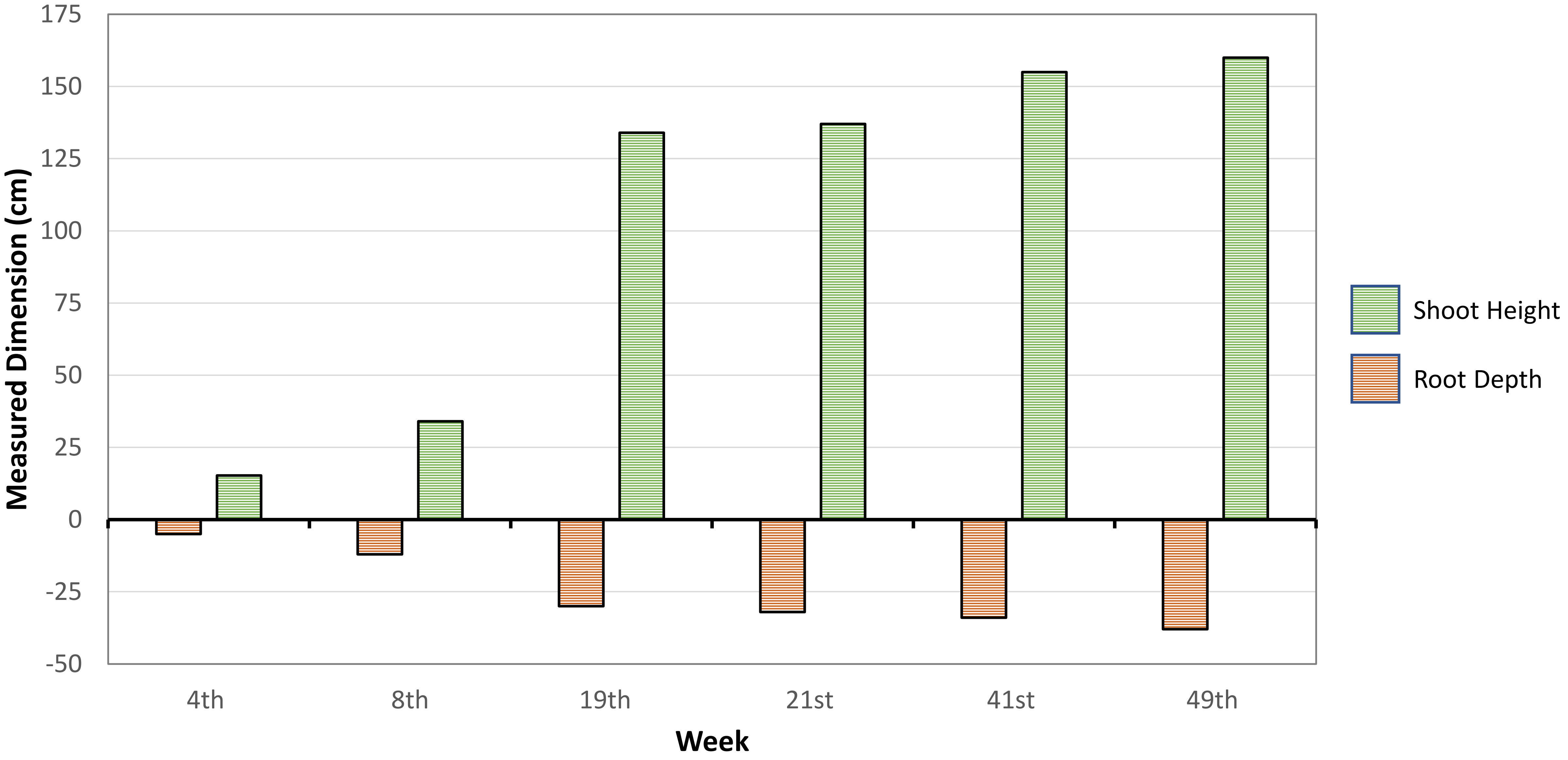
VG, Week 8

VG, Week 12

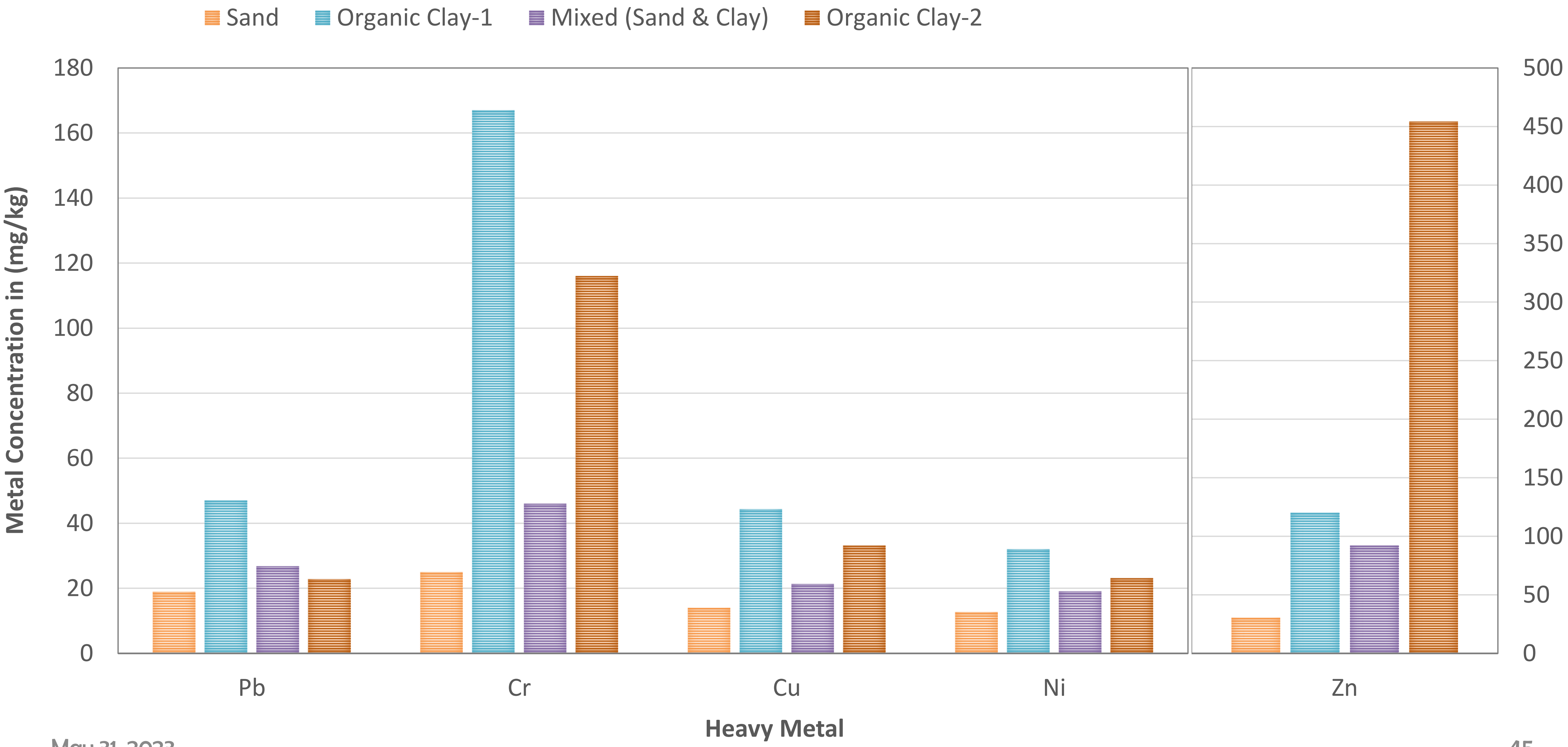
VG, Week 20

Vetiver Grass Plot

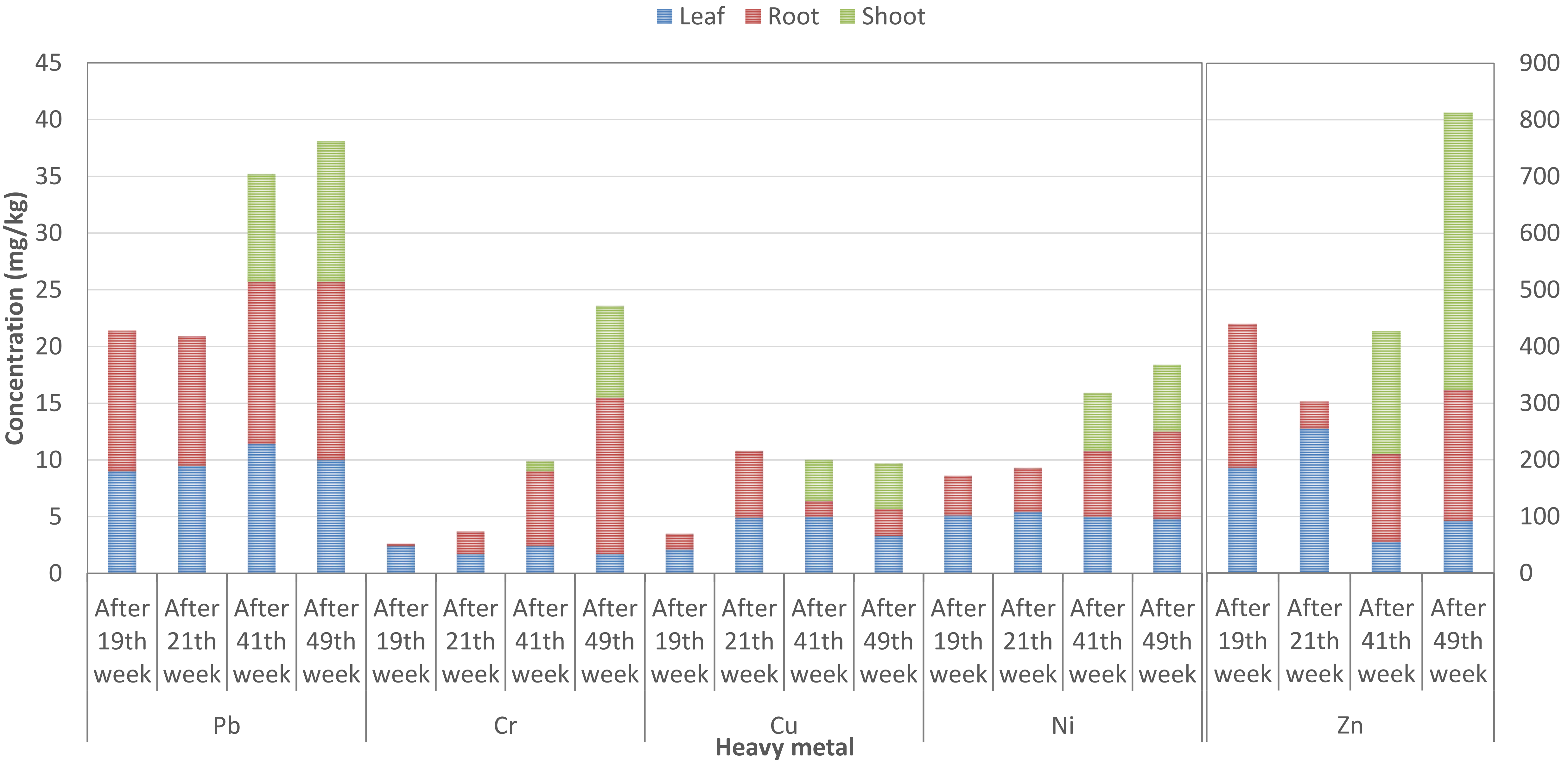
Growth Study: Vetiver Grass



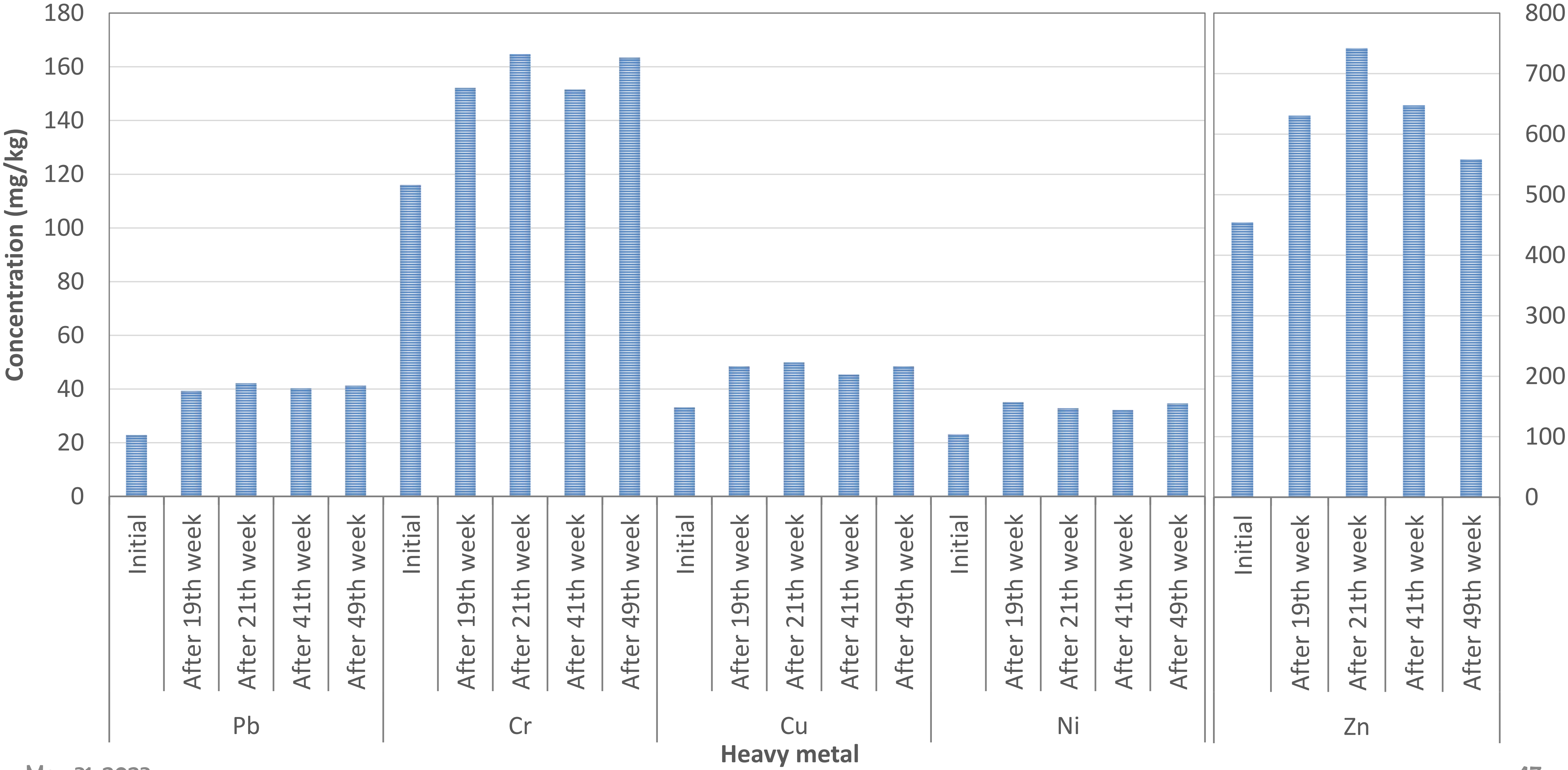
Initial Concentration in Soil



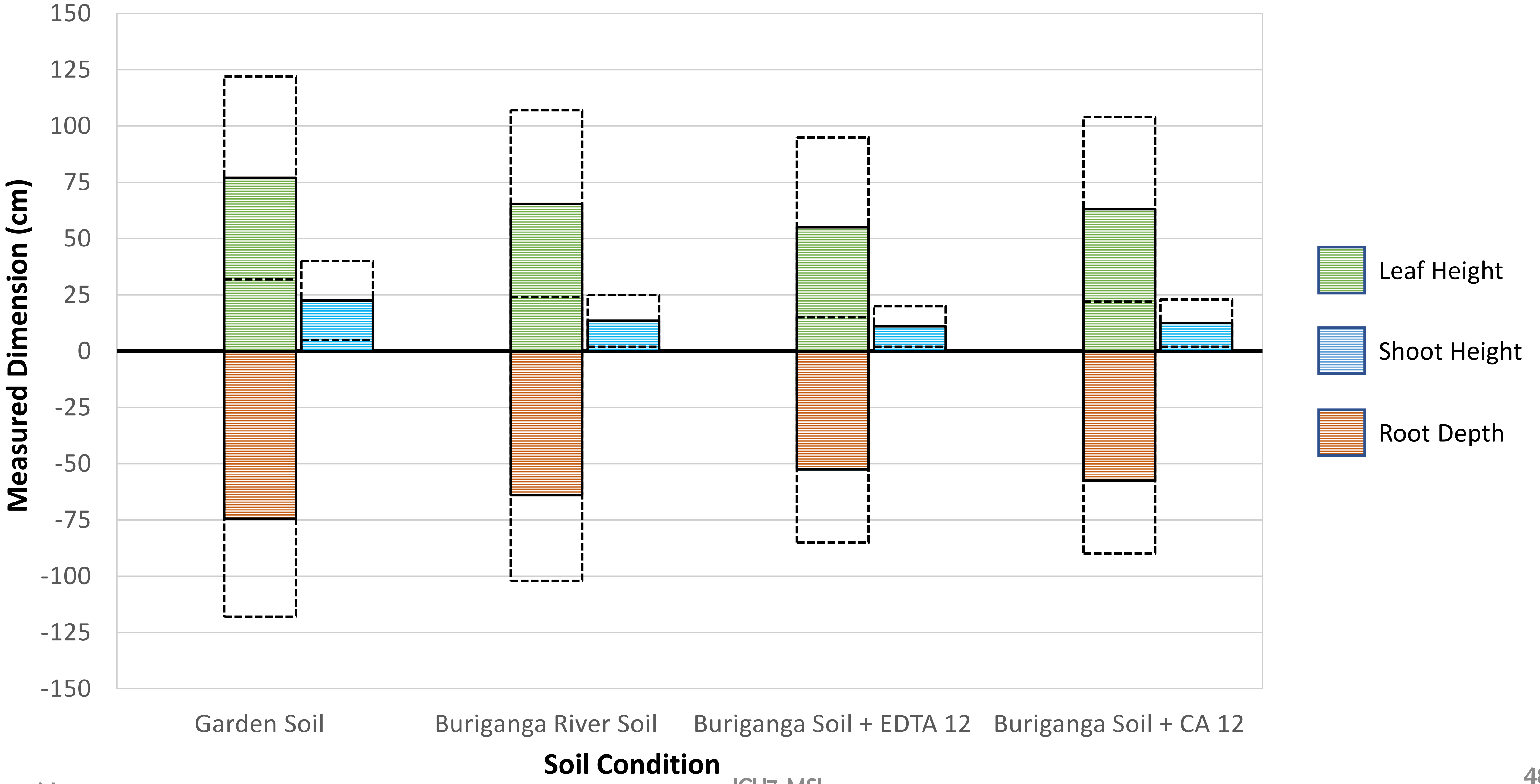
Concentration in Vetiver Plant



Concentration in Soil After Harvesting



Growth Study: Vetiver at 13th Week



Summary

- Despite significant uptake of contaminants by vetiver, the before and after scenario appears to be contradictory. The tray was filled with contaminated soil collected from the natural source and the distribution of contamination might not be homogeneous throughout the sample. This might be the fact behind such large variations (Islam, 2023).
- The heavy metal uptake efficiency of vetiver grass is not as good as other locally available hyperaccumulators, its uptake efficiency can be substantially enhanced with application of chelating agents (EDTA or citric acid).
- In case of EDTA, uptake efficiency did not increase significantly beyond a particular dosing value (1-2 mmol/kg of soil) and for higher value caused discoloration of leaves (Dey, 2016).
- Uptake efficiency gradually increased with increasing dosing level of citric acid (Dey, 2016). But the uptake efficiency of heavy metals by using citric acid increased with increasing dosing level. From the analysis, it is evident that vetiver can be used as a continuous phytoextractor or phytostabilizer. However, it requires an in-depth analysis considering extent and level of treatment, life cycle analysis, survivability in various environmental and soil conditions, etc.

Phytoremediation of Buriganga Riverbed Sediment

Objectives

To compare the growth of Indian Mustard and Marigold in heavy metal-contaminated sediment with that in normal garden soil (control condition). To assess temporal variation in heavy metal uptake by Indian mustard and Marigold from the Buriganga riverbed sediment.

Average high and low temperature: 26°C and 13°C

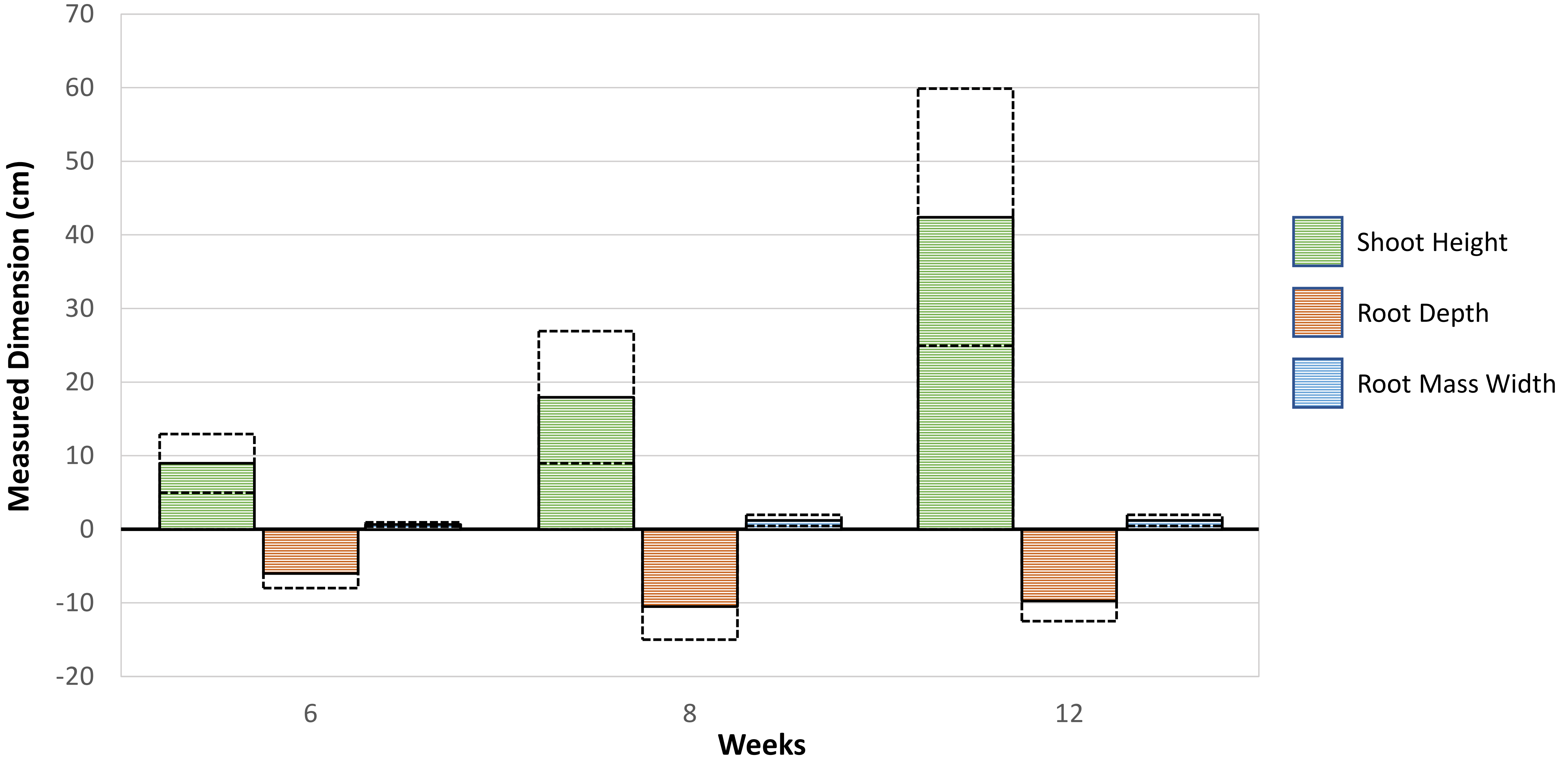
Average photosynthetic flux: 375 µmol m^{-2} s^{-1}

Average relative humidity: 50%

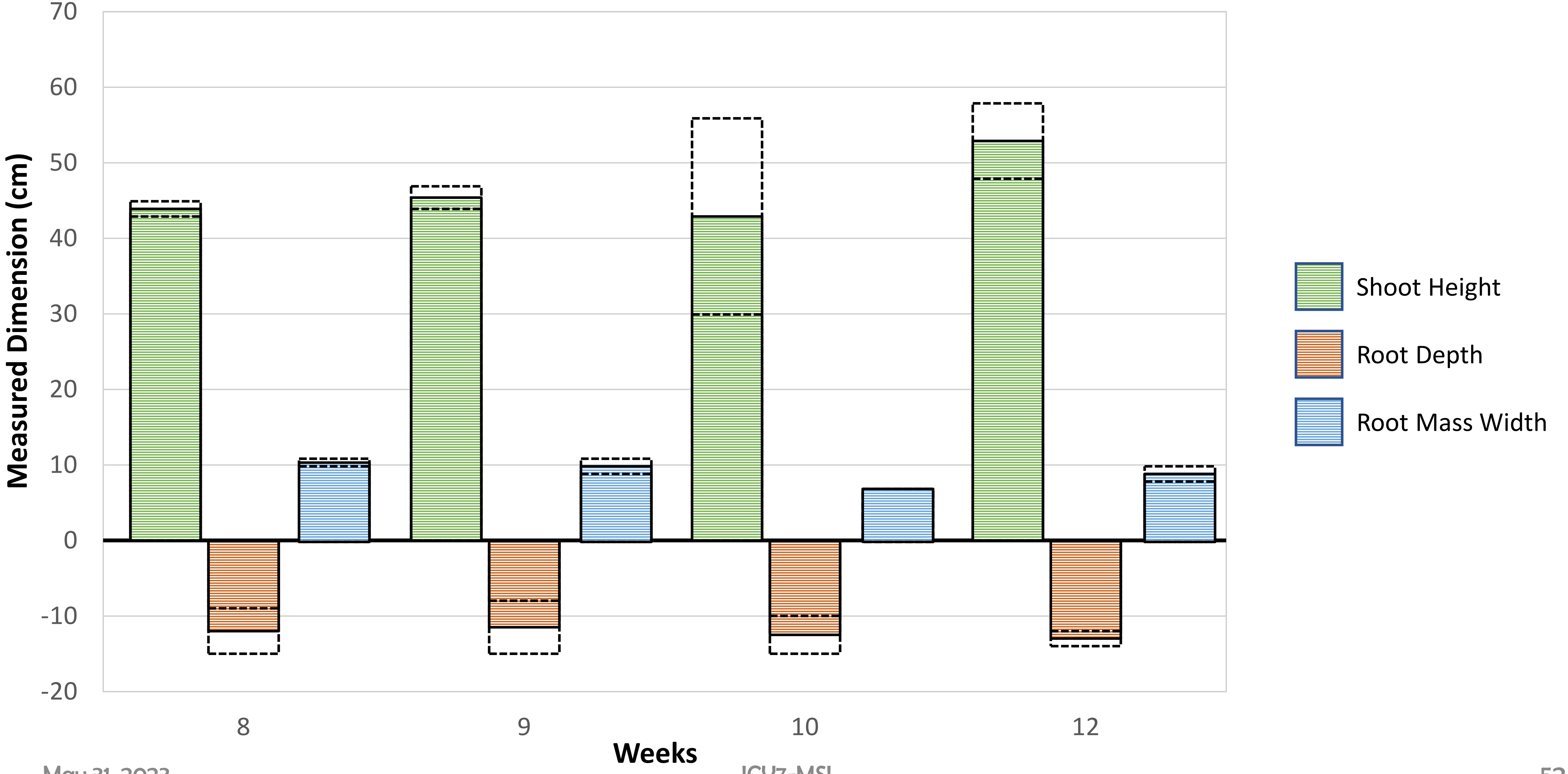
Physical Properties of Buriganga Riverbed Sediments and Garden Soils

Sample	LL (%)	PL (%)	PI (%)	Specific Gravity (G_s)	OC (%)	Silt (%)	Clay (%)
Buriganga riverbed sediment	46	23	23	2.67	4-6	91.5	8.5
Garden soil	49	18	31	2.70	-	58	17

Growth Study: Indian Mustard

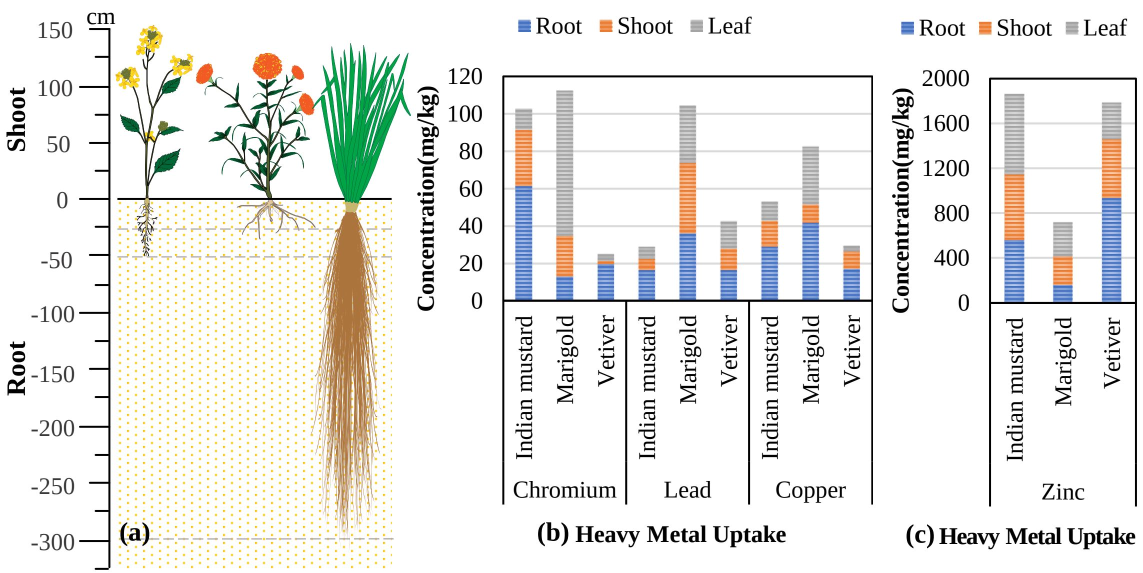


Growth Study: Marigold



Results and Discussions (Comparison)

Comparison of total uptake of Indian Mustard, Marigold, Vetiver Grass in 12-13 weeks time



(b) Heavy Metal Uptake

(c) Heavy Metal Uptake

- Vetiver has a lower efficiency of heavy metal uptake compared to Indian mustard and marigold plants. Marigold was observed to be more efficient for Cr, Pb, and Cu uptake, while Indian mustard was found to be more effective for Zn uptake (Choudhury et al., 2016).
- However, vetiver showed better performance in uptaking Zn than marigold while it was similar to the effectiveness of Indian mustard. Here, the root depth of Indian mustard and marigold is about 10-15cm whereas the vetiver has a root depth of about 50-70cm.
- Therefore, vetiver has an advantage of having a large and extensive root system with higher biomass compared to these plants, and this can lead to the remediation of contaminants from a deeper and wider influence zone.

Cleaning of Wasteland

Background

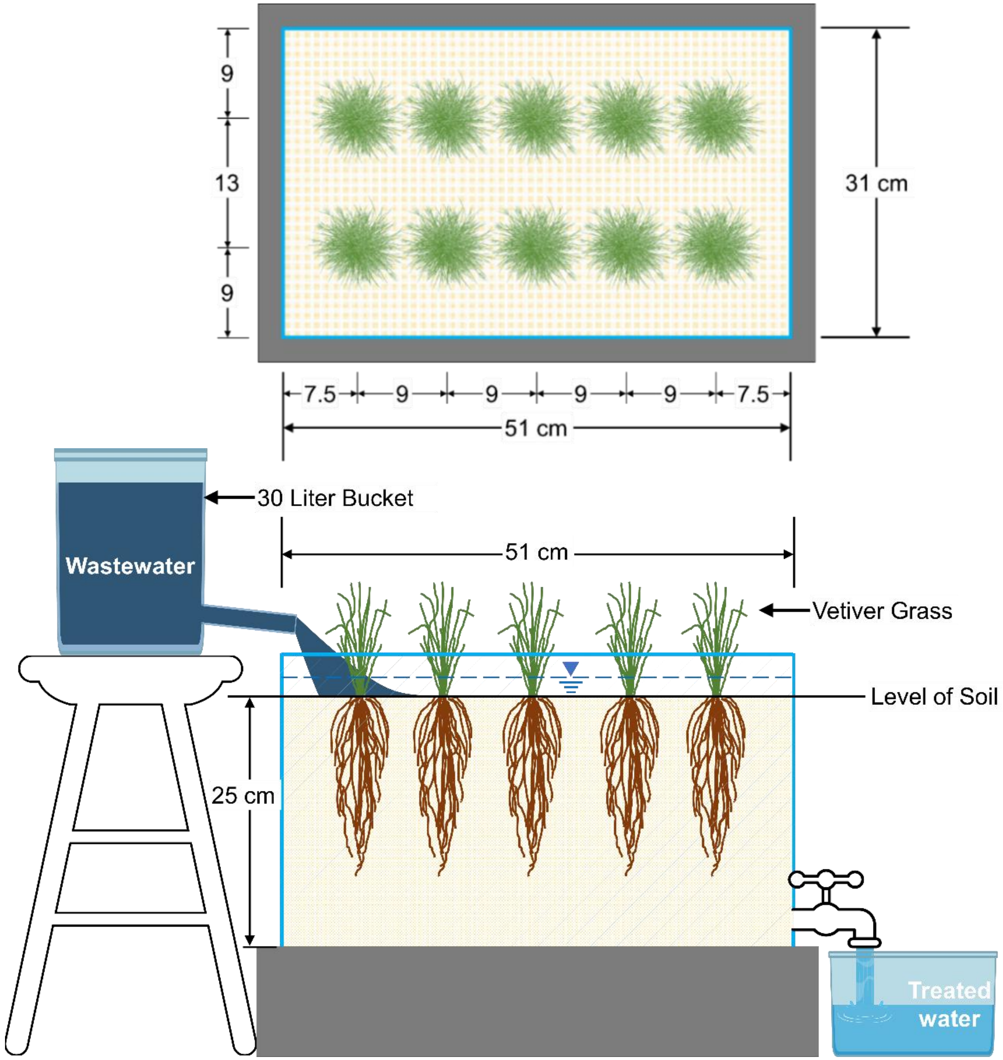
Dhaka has 19 main discharge points, primarily located near canals and drains. Unfortunately, these areas have become dumping grounds for waste, which has resulted in a polluted environment rather than a refreshing one. The haphazard disposal of solid waste into low-lying areas and canals exacerbates the degradation of soil quality.

Objectives

- To assess the growth of vetiver in wasteland.
- To represent the effectiveness of plant in removing target contaminants (e.g., ammonia, phosphate, organic matter) from polluted soil and water.

Experimental Setup

Details of the plantation



Schematic diagram of waste treatment by vetiver grass

Experimental Setup with Normal water

Experimental Setup with Wastewater

(Islam et al., 2018)

Results and Discussions

Specific Gravity	Liquid limit (%)	Plastic limit (%)	Shrinkage limit (%)	Plasticity index
2.55	40	22	26	18
Flow index	**Co-efficient of uniformity**	**Co-efficient of curvature**	**Fineness modulus**	**Classification of soil**
16	2.24	0.62	2.93	CL

Quality Parameters of Wastewater and Treated Water

Water Quality Parameters	Raw Wastewater (mg/L)	Treated Water (mg/L)	Percentage Removal	Percentage Generated
NH_3	26.0	1.00	96	
NO_2	1.0	0.33	68	
NO_3	1.1	2.70		60
PO_4	16.2	0.75	95	
COD	81.0	176.0		54
pH	7.6	7.8		

Findings of the Study

It was found that the wastewater contains NH_3 of 26 mg/L, $PO4^-$ of 16.2 mg/L and the COD of 81.0 mg/L (Islam et al., 2018). Results from soil and water quality parameter tests reveal that vetiver removes NH_3 and $PO4^-$ in substantial amount i.e., 96% and 95%, respectively. It means that vetiver can play a major role in remediating wasteland. It implies that vetiver-based phytoremediation technique can be useful for surface water treatment of contaminated *khals*.

Arsenic Remediation

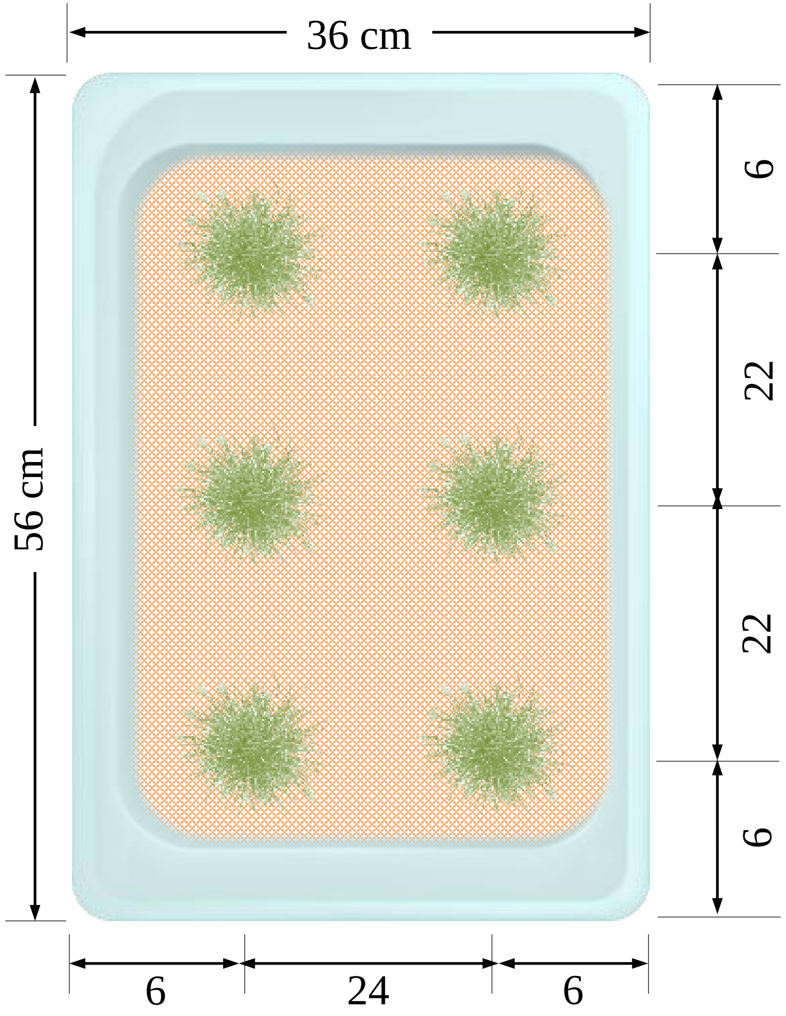
Background

- Arsenic contamination from irrigation and mining is a significant issue in South and Southeast Asia, including Bangladesh, with the problem being particularly pronounced in anaerobic conditions of flooded paddy fields. This contamination has resulted in severe consequences for local communities.
- Numerous studies have explored the remediation of arsenic contamination using local grasses and plants, but the potential of the vetiver plant for arsenic remediation remains to be fully investigated.

Objectives

To observe the growth of vetiver grass in As contaminated agricultural top soil. To investigate the effectiveness of vetiver grass in As removal.

Experimental Setup



Schematic Diagram Showing Vetiver Plantation

Arsenic Contaminated Soil | Nursery Soil

Vetiver Plantation in Nursery and Arsenic Contaminated Soil

(Islam et al., 2016)

Findings of the Study

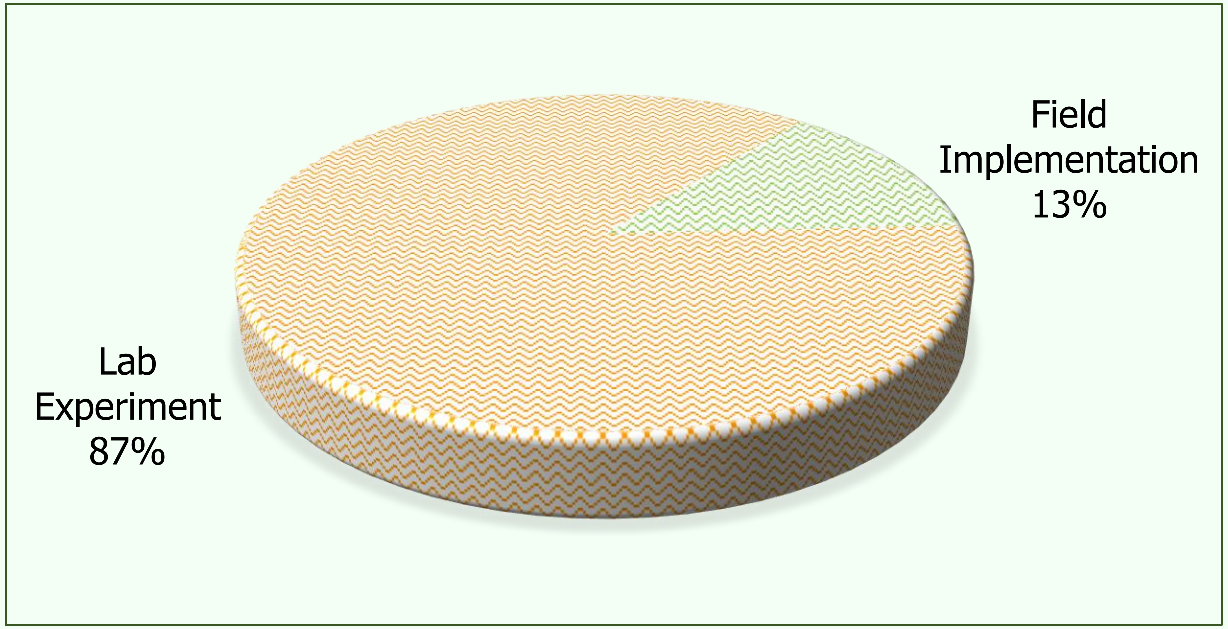
- The growth of vetiver was better in the contaminated soil compared to the control soil which might be due to the higher nutrient content in the contaminated soil, Islam et al. (2016).
- The arsenic content in the contaminated soil before plantation was found to be 18.8 mg/kg. After 6 months of plantation, it was found that arsenic contamination of the soil varies between 13.6 and 15.2 mg/kg. It means that vetiver can uptake As from the contaminated soil by 23% over time. Srisatit et al. (2003) also showed similar results.
- However, the uptake is not significant, more research works are required including the additives such as EDTA, AMF, citric acid, etc. as indicated by Caporale et al. (2014).

04

Research Gaps and Future Direction

Key Findings from Literature Review

- The potential and effectiveness of vetiver grass in the removal of heavy metals, POPs, PCB etc., and its comparison with other methods and plants have been noticed in the reviewed articles. Moreover, the field experiment presented out of the reviewed articles proves that the vetiver-based phytoremediation technique is effective in the removal of contaminants.
- The potential of vetiver grass in the removal of different heavy metals and toxins like dioxin, cyanide, TNT etc. has been assessed firsthand in different countries in field implementation.
- Further lab and field experiments and monitoring are required to identify gaps, and application viability and to develop guidelines for safe and cost-effective technology.



Year: 2000-present
No. of Reviewed Articles: 52
Lab Experiment: 45
Field Implementation: 7

Gaps in the Remediation Sector

Knowledge Gaps

1. **Policy, Legislative and Regulatory Gaps**
   (i) In most cases, soil pollution is not legally defined or recognized.
   (ii) In several countries industrial activities that pollute soil are not consistently regulated.
   (iii) Securing fund is another gap.
   (iv) There are limitations in the creation of key institutions and/or integration between institutions.
2. **Policy Gaps**
   (i) Slow or incomplete transfer of knowledge from scientists and enforcement agencies to policymakers
   (ii) The lack of generally accepted threshold values for toxicity assessment of priority and emerging contaminants

Main Constraints to Tackle Soil Pollution

1. **Lack of Awareness**
   (i) Socio-economic limitations
   (ii) Lack of national and local campaigns
   (iii) Lack of detailed studies
2. **Lack of Political Will and Illegal Waste Disposal**
   (i) Political pressures from other sectors, and the possible economic impact of control measures
   (ii) Illegal dumping and import of toxic wastes from other countries
3. **Lack of Infrastructure and Capacity**
   The Asia–Pacific region is very heterogeneous, with each country having different infrastructures and capacities for soil pollution management. These constraints often result in a technical inability to create and improve regional or global contaminant inventories.

FAO and UNEP (2021)

Standard Reporting Format

To have a complete idea of a study, a comprehensive and thorough reporting format should be followed where all the necessary data are collected and compiled in a standard way and using similar units. The following information can be collected to make the reporting useful and all-inclusive,

1. Geographical location with GPS
2. Climatic data (rainfall, temperature, daylight, humidity, seasonal distribution etc.)
3. Soil data (soil texture, pH, Cation Exchange Capacity (CEC), Electric Conductivity (EC), organic matter and nutrient content of the soil such as Total Nitrogen, Boron, Potassium, Phosphorus, Zinc)
4. Season and duration of the study
5. Details of amendments, if any (fertilizer, additives, fungi etc.)
6. Concentration of heavy metals before treatment
7. Concentration of heavy metals after treatment (during harvesting time and throughout multiple seasons)
8. BCF, Concentration of Heavy Metals in plant Shoots and Roots, Phyto-method

05

Way Forward and Summary

Way Forward

- **Research and Development:** Addressing soil contamination issues, particularly in Asian countries, requires focused research on the application of nature-based solutions at a field scale. This should involve a thorough investigation of various environmental and soil conditions, as well as the growth and effectiveness of different plants, to inform decision-making on the most suitable remediation options. Furthermore, a comprehensive analysis of existing contamination level assessment criteria is necessary to ensure their continued relevance. Consequently, political leaders and governments should allocate sufficient funding to this vital field of study, given its significant implications for human health and well-being.

- **Collaboration**: To address soil contamination issues, a multi-disciplinary collaboration involving agricultural scientists, engineers, academics, and government agencies at both local and international levels is required. This collective effort is essential for developing effective guidelines, construction methodologies, and ensuring large-scale adaptation and successful application with active involvement from community members.

- **Resource Development:** In addition to collaborative research, legislative enforcement is necessary for the assessment and identification of contaminated sites, which requires the development of resources including trained scientists, contractors, skilled labor, and equipment.

Summary

- Rapid economic growth in Asian countries, including Bangladesh, has led to increased urbanization and industrialization, causing significant environmental pollution, particularly with toxic and carcinogenic soil chemicals. In Bangladesh, soil and water contamination, primarily due to POPs and heavy metals has led to serious health concerns for local populations. Furthermore, land degradation and erosion have become significant geo-environmental issues in these regions. These issues are also hampering the SDGs. To mitigate these issues, it is critical to implement soil remediation measures and reduce land degradation and erosion, for which the author has extensively researched the use of vetiver grass as a nature-based solution, verified through lab tests, physical modeling, and field applications.
- The author has explored the use of various plants and grasses, particularly vetiver grass, for the phytoremediation of heavy metals from different soils. Initially, vetiver's heavy metal uptake was lower compared to other local hyper-accumulators but improved significantly when chelating agents were introduced. They also assessed other plants like Indian Mustard and Marigold, with Marigold showing higher uptake efficiency for Cr, Pb, and Cu, while Indian Mustard was more efficient for Zn uptake. Despite its lower efficiency, vetiver grass has advantages such as a larger root system, higher biomass, and longer lifespan. However, to ascertain the suitability of these plants for wider use, comprehensive analysis considering treatment levels, life cycle, and adaptability to various geo-environmental conditions is required.

Summary

- Past research shows promise for the use of vetiver in soil remediation, particularly for heavy metal contaminants. Despite these encouraging findings, there is a lack of large-scale field applications and consistent reporting and assessment methodologies. Moreover, the current guidelines for soil contamination levels may be outdated. While phytoremediation, especially using vetiver, has proven effective in various geo-environmental conditions in lab experiments, broader implementation is constrained by these gaps.
- Inconsistent reporting and assessment criteria also hinder its applicability. Hence, there exists significant potential for further research in this area to improve understanding and usability.
- Legislative measures and public awareness are critical in tackling soil and water contamination. Addressing policy, legislative, and regulatory gaps, along with the mobilization of resources such as scientists, contractors, and skilled labor is crucial for effective remediation efforts. Further, political will and public engagement are necessary to reduce contamination levels and ensure the success of nature-based solutions.

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Thank You