DISCOVERY

Effect of polluted soil on seedling growth and development of *Phaseolus vulgaris* L

Muhammad Zafar Iqbal, Muhammad Hamza Khan, Muhammad Shafiq*

To Cite:
Iqbal MZ, Khan MH, Shafiq M. Effect of polluted soil on seedling growth and development of *Phaseolus vulgaris* L. *Discovery* 2023; 59: e27d1028

Author Affiliation:
Department of Botany, University of Karachi, Karachi-75270, Pakistan

***Corresponding Author**
Department of Botany, University of Karachi, Karachi-75270 Pakistan
Email: shafiqeco@yahoo.com
ORCID: 0000-0002-0488-8946

Peer-Review History
Received: 11 January 2023
Reviewed & Revised: 14/January/2023 to 10/February/2023
Accepted: 12 February 2023
Published: March 2023

Peer-Review Model
External peer-review was done through double-blind method.

Discovery
pISSN 2278–5469; eISSN 2278–5450

URL: https://www.discoveryjournals.org/discovery

© The Author(s) 2023. Open Access. This article is licensed under a Creative Commons Attribution License 4.0 (CC BY 4.0)., which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made. To view a copy of this license, visit http://creativecommons.org/licenses/by/4.0/.

DISCOVERY SCIENTIFIC SOCIETY

ABSTRACT

The environmental degradation is an alarming issue of the developed and particularly for under developed countries. The ever increase in addition of the pollutants in the environment producing air, water and soil pollution problem. Soil pollution is worldwide problem due to industrial, anthropogenic and modern civilization activities and important concern for plants growth. The discharge of pollutant from different industries in river is a potential source of soil pollution and affecting the quality of soil. The aim of the present study was to ascertain the effect of polluted soil on seedling growth characteristics of an important agricultural crop, kidney bean. The result of the present studies showed a high percentage of decrease in root, shoot and seedling length of kidney bean with the treatment of polluted soil (T4) at 100% polluted soil concentration. The treatment of polluted soil at (T1) increased (+6.06) leaf area at 25% concentration of polluted soil. Increased in polluted soil at T2, T3 and T4 treatment progressively decreased leaf area of kidney bean as compared to control. The highest percentage of reduction in root, shoot and total seedling dry weight of kidney was found with the treatment of T4 as compared to control. The seedling vigor index in response to polluted soil treatment (T1), (T2), (T3), (T4), (T5) was recorded 324.60, 308.20, 104, respectively and 97.8 as compared to control 567.

Keywords: Agronomic growth, Kidney bean, seedling dry weight, seedling vigor, soil pollution

1. INTRODUCTION

Soil pollution is an important concern for healthy environment plant growth. Soil is one of the most important natural resources for food production globally and major geochemical sink of pollutants (Biggelaar et al., 2003; Shi et al., 2022). Industrial and anthropogenic activities adversely affected the soil's productivity, physical and chemical properties and quality. Soil type, sunlight, nutrients and fresh water are essential and can govern plant life (Martonas, 2012). Environmental pollution is a global issue and formed an adverse effect on land and water and has health hazards to human, animals, plants and ecosystem (Al-Dulaimi et al., 2012; Wu et al., 2018). Pollution of urban soils by addition of toxic element has become the focus of social concern and worldwide concern due to common sources such as rapid urbanization, atmospheric deposition, agricultural, emerging industrial hub, traffic activities, natural sources, human activities and human health concern (Das et al., 1998; Taati et al., 2020; Yuan et al., 2021; Vega et al., 2022; Yang et al., 2022; Li et al., 2023; Zeng et al., 2023).

In the literature the impact of soil pollution on soil resources degradation, food security, harm to human health, biodiversity and accumulation of toxic element in vegetable reported (Oliver and Gregory, 2015; Rodríguez-Eugenio et al., 2018; Zwolak et al., 2019; Raimi et al., 2022; Wu et al., 2022; Vázquez-Arias et al., 2023). The Zarjoub and Goharroud river basins in northern Iran due to exposure to various types of pollution sources found most polluted rivers in Iran. The irrigation for paddy fields showed the high concentrations of eight PTEs (As, Co, Cr, Cu, Mn, Ni, Pb and Zn) in channel bed sediment and concluded that Industrial/agricultural effluents, municipal wastewater, leachate of solid waste, traffic-related pollution and weathering of parent materials were found to be responsible for pollution of the Zarjoub and Goharroud watersheds (Haghnazar et al., 2023). The leguminosae is one of the well-known plant family in plant kingdom. *Phaseolus vulgaris* L. is family member of Leguminosaceae. *P. vulgaris* is an important pulse crop and well known for source of proteins, fibers and vitamin, mineral for human diet and grown worldwide (Celmeli et al., 2018; Justino et al., 2019; FAO, 2019).

High rate of increase in population density and industrial growth are adversely affecting physical, chemical and biological properties of soil. It is important to understand the effect of soil pollution on crop growth. Interest in the quality and productivity of soil and its effects on crop has been increased since last couple of decades by researchers. Such types of studies on *P. vulgaris* on this aspect are few in the country. The farmer of the area gets assistance for the cultivation of crops from the two main river Lyari and Malir of the Karachi, city. A research study was carried out to find out the effects of different concentration of polluted soil on germination and seedling growth of kidney bean. The present study was carried out with the aim to find out the effects of polluted soil using different concentration of polluted soil on seedling growth and biomass production of *P. vulgaris*. The tolerance indices and seedling vigor index of kidney bean in response to soil pollution was also calculated.

2. MATERIALS AND METHOD

The soil samples were collected from two different sites. One from garden of Karachi University Main Campus and other from the bank of Lyari River. The Lyari River flows from north east of Karachi to the central districts and drains into the Arabian Sea at Manora Channel. Until the 1950's the river had clean water with farming activities on its bank. The rapid growth of the city, industries and population the river ecology was transformed to discharge wastewater, sewage and industrial effluents. Approximately 2,200 industrial units are situated around the Lyari River. The Lyari River is a key contributor and an estimated amount of 200 million imperial gallons of raw sewage that enter Arabian Sea. Major wastage is dumped from leather tanning, pharmaceutical, petrochemical, chemical and textile industries. Healthy and viable seeds of kidney bean were collected from the market and their viability and percentage of germination was pre-tested in a petri dish to obtain a uniform germination and growth in soil samples. After the collection of soil sample from above mentioned site, the soil was air dried for 48 hours, grounded and then after removing pebbles and twigs the soil samples were passed through a 2.0 mm iron sieve. The ratios of soil composition were as Table 1.

Table 1 The composition of polluted and unpolluted (Garden soil)

Treatment	Polluted soil (%)		Garden soil (%)
T1	0% polluted soil	+	100% garden soil
T2	25% polluted soil	+	75% garden soil
T3	50% polluted soil	+	50% garden soil
T4	75% polluted soil	+	25% garden soil
T5	100% polluted soil	+	0% garden soil

The experiment was conducted in a greenhouse at the Department of Botany, University of Karachi. The range of maximum temperature and minimum temperature was 22-31°C and 11-18°C and atmospheric humidity during the experiment was in the range of 14-88%. The weather outlook was mostly sunny with a range of 10:30 to 11:41 hour's sunshine. Healthy seeds of *Phaseolus vulgaris* L. (Kidney bean) were taken from local market. The seeds of kidney bean were sterilized with aqueous mercuric chloride (0.1%) for 5 minutes to avoid fungal contamination and thoroughly washed with distilled water. The seeds were sown at 1 cm depth in plastic pots of 7.3 cm diameter and 9.6 cm in depth in different concentration of polluted soil (Table 1). The pots were irrigated daily with tap water until the soil is completely soaked. Each pot prepared by filling the soil by 2/3 in pot and punching of one hole in the bottom. A total of 25 pots were randomly divided into five groups for polluted and unpolluted soil composition and marked on pot as (T1), (T2), (T3), (T4), (T5).

There were five replicates for each treatment and the experiment was completely randomized. Every week, pots were reshuffled to avoid light/shade or any other greenhouse effects. After five weeks, seedlings were carefully removed from the pots and washed thoroughly to measure root, shoot and seedling length (cm). Leaf area, root/shoot ratio, leaf weight ratio, leaf area weight ratio was also recorded. Root, shoot and leaves were separated for drying in an oven at 80°C. The effects of polluted soil on biomass production (leaf fresh weight (g), root dry weight (g), shoot dry weight (g), leaves dry weight (g) and total seedling dry weight (g) of kidney bean seedlings were also noted. The germination potential was determined by computing a seedling vigor index (S.V.I.) as prescribed by (Bewly and Black, 1982). The data collected from various growth indices were analyzed by standard statistical technique.

Leaf weight ratio was determined according to the Equation 1.

Leaf weight ratio = Leaf dry weight/Total plant dry weight. (1)

Percentage reduction in seed germination and seedling growth parameter was calculated as per Equation 2.

C-T X 100 (2)
T

Where, C= Control T= T treatment

The tolerance indices were determined by the following formula

Soil pollution tolerance index = Mean root length in polluted soil treatment/Mean root length in unpolluted soil treatment X 100 (Equation 3)

3. RESULTS AND DISCUSSION

Soil pollution has increased over the last few years very rapidly (Cachada et al., 2018). The result of the present studies showed different impact on seedling growth and biomass production of kidney bean when treated with different level of polluted soil (Table 2; Figures 1 - 5). Germination is the initial stage of a plant life cycles (Tsegay and Gebreslassie, 2014). A pronounced variation in shoot length (9.8 – 5.98 cm), root length (9.10 – 3.80 cm), total seedling length (18.90 – 9.78 cm) and leaf area (0.35 – 0.12 cm^2) of kidney bean was recorded (Table 2). Plants have to cope with abiotic stresses to contaminated soil (Rady et al., 2023). Similar trend in shoot dry weight (0.29 – 0.07 g), root dry weight (0.003 – 0.048 g), total seedling dry weight (0.016 – 0.108 g) was recorded to polluted soil stress. An increase in leaf area weight ratio and leaf specific area of kidney bean in soil polluted treated soil was observed.

Table 2 Seedling growth performance of *Phaseolus vulgaris* L. in different concentration of polluted soil

	Soil Types				
Parameter	T1	T2	T3	T4	T5
Shoot length (cm)	9.80	8.23	8.11	6.20	5.98
Root length (cm)	9.10	8.0	7.30	4.20	3.80
Leaf area (sq. cm2)	0.33	0.35	0.24	0.13	0.12
Total seedling length (cm)	18.90	16.23	15.41	10.40	9.78
Total seedling fresh weight (g)	0.380	0.312	0.150	0.110	0.092
Shoot fresh weight (g)	0.29	0.25	0.10	0.08	0.07
Root fresh weight (g)	0.09	0.062	0.05	0.03	0.02
Leaf fresh weight (g)	0.03	0.02	0.02	0.01	0.002
Root dry weight (g)	0.048	0.040	0.020	0.010	0.003
Shoot dry weight (g)	0.29	0.25	0.10	0.08	0.07
Leaf dry weight (g)	0.002	0.0013	0.0014	0.0008	0.0007
Total seedling dry weight (g)	0.108	0.099	0.048	0.03	0.016

Root – Shoot ratio	0.80	0.67	0.71	0.50	0.23
Leaf weight ratio	0.07	0.06	0.13	0.10	0.02
Leaf area weight ratio	0.86	1.12	1.60	1.20	1.30

Soil Treatment: Symbol used= T1= 0% polluted soil + 100% garden soil
T2=25% polluted soil + 75% garden soil, T3=50% polluted soil + 50% garden soil
T4=75% polluted soil + 25% garden soil, T5=100% polluted soil + 0% garden soil

Soil treatment (T2) produced lowest percentage of decrease in shoot length (16.02%), root length (11.22%), seedling length (14.12%) and increased leaf area (6.06%) of kidney bean seedling as compared with control soil treatment. Soil treatment (T3) produced further decrease shoot length (17.24%), root length (19.78%), seedling length (18.46%) and leaf area (27.27%) of kidney bean seedling as compared with control soil treatment. Soil treatment (T5) produced highest percentage of decrease in shoot length (38.57%), root length (58.24%), seedling length (48.25%) and leaf area (62.50%) of kidney bean seedling as compared with control soil treatment.

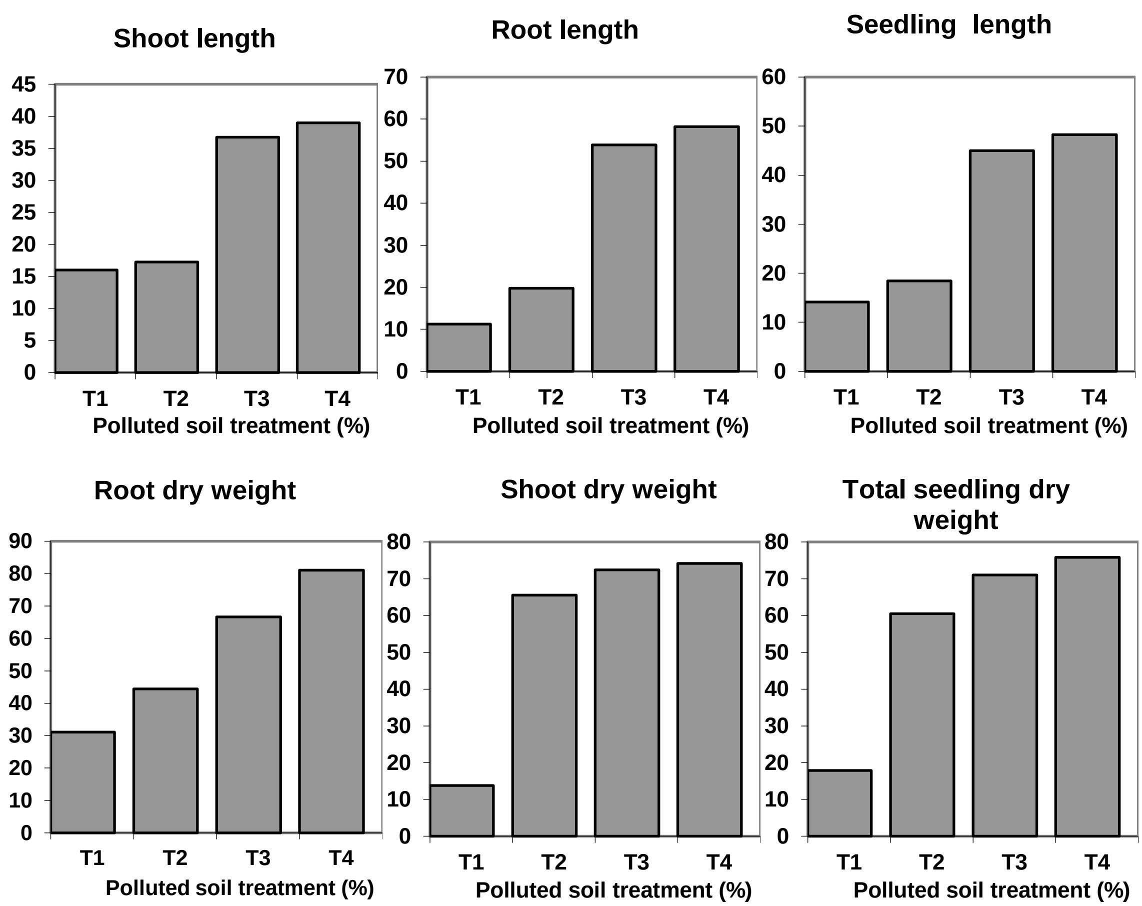

Figure 1 Percentage decrease in shoot, root, seedling length, root, shoot, total seedling dry weight (g) of kidney bean in response to different concentration (T1, T2, T3 and T4) of polluted soil as compared control. (T1=25% polluted soil + 75% garden soil, T2=50% polluted soil + 50% garden soil, T3=75% polluted soil + 25% garden soil, T4=100% polluted soil + 0% garden soil).

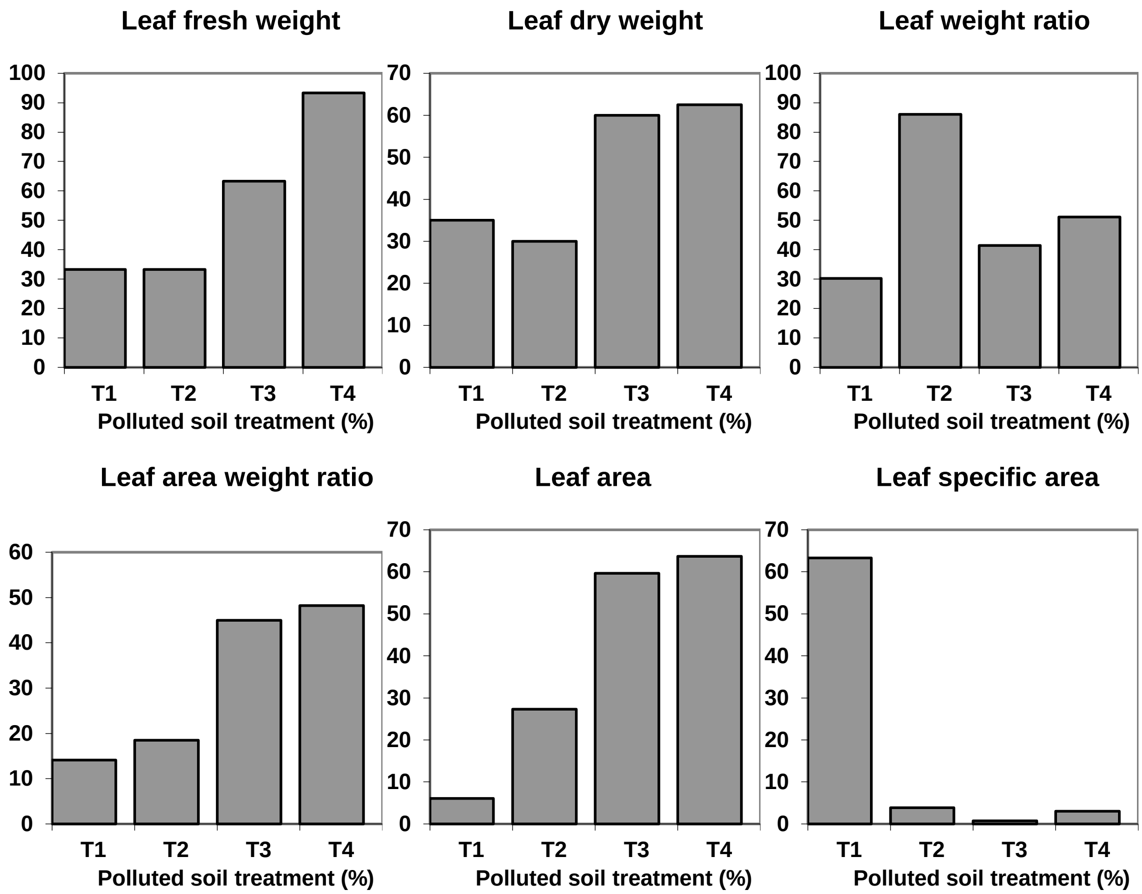

Figure 2 Percentage decrease in leaf fresh weight, leaf dry weight, leaf weight ratio, leaf area weight ratio, leaf area and leaf specific area of kidney bean in response to different concentration (T1, T2, T3 and T4) of polluted soil as compared control. (Symbol used T1=25% polluted soil + 75% garden soil, T2=50% polluted soil + 50% garden soil, T3=75% polluted soil + 25% garden soil, T4=100% polluted soil + 0% garden soil).

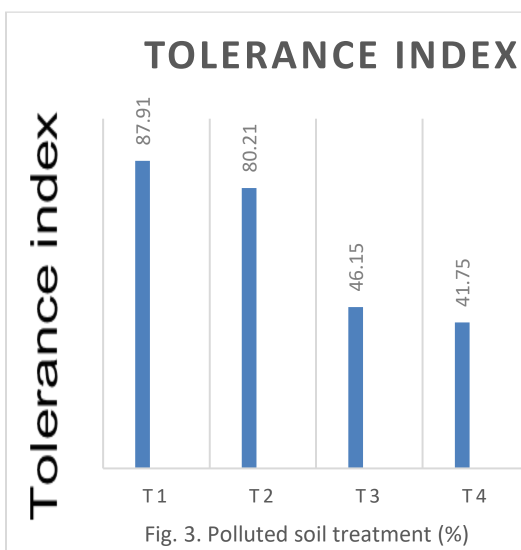

Figure 3 Tolerance index percentage for kidney bean in response to different concentration (T1, T2, T3 and T4) of polluted soil as compared control. (T1=25% polluted soil + 75% garden soil, T2=50% polluted soil + 50% garden soil, T3=75% polluted soil + 25% garden soil, T4=100% polluted soil + 0% garden soil).

Soil contamination and tolerance to soil pollution for agronomic crops are receiving attention globally. According to tolerance test, the seedlings growth of kidney bean showed high percentage of tolerance index (87.91%) at 25% concentration of polluted soil treatment as compared to control (Figure 3). The seedlings growth of kidney bean showed the lowest percentage of tolerance index (41.75%) at 100% of polluted soil treatment as compared to control was recorded.

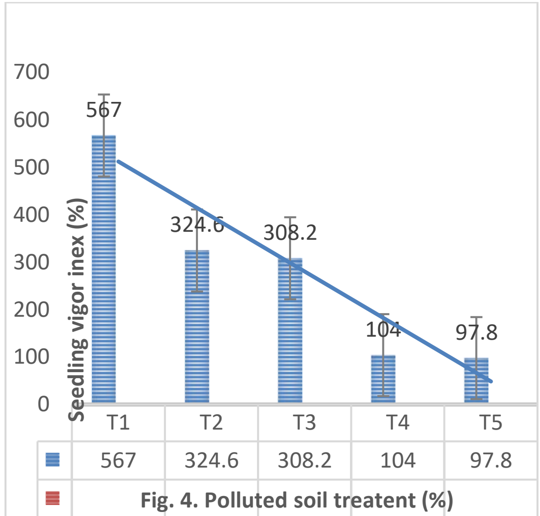

Figure 4 Percentage of seedling vigor index of kidney bean in response to different concentration (T1, T2, T3, T4, T5) of soil. (Symbol used T1=25% polluted soil + 75% garden soil, T2=50% polluted soil + 50% garden soil, T3=75% polluted soil + 25% garden soil, T4=100% polluted soil + 0% garden soil).

The high value percentage of seedlings vigor index (567) of kidney bean was recorded in control soil treatment. The lowest (97.80) seedling vigor index percentage for kidney bean seedlings was recorded with the treatment of T5 as compared to control (Figure 4). In another study, the detrimental impact of polluted soil on seedling vigor of cashew (*Anacardium occidentale* L.) recorded and suggested to increase public awareness on the role soil pollution in our terrestrial ecosystem (Faluyi, 1986).

The treatment of crude oil contaminated soil hindered germination, development, reduced heights, girths, yield and agronomic growth performance of *Abelmoschus esculentus* L. (Oyedeji et al, 2012). The soil is the main reservoir of the mineral and nutrients. The addition of toxic materials in soil due to human and industrial activities influenced on the physical and chemical characteristics of the soil and affect plant growth. This type of waste is hazardous to ecology of the area. In present studies, the effects of different concentration T2-T5 of polluted soil showed variation in seedling growth and productivity performance of kidney bean as compared to control (T1). Variation in seedling growth performance of kidney bean seedlings can be attributed with the increase in polluted concentration of soil. *P. vulgaris* seedlings initially showed some adaptability indicating with the increase in specific leaf area. The availability of toxic pollutants in soil and uptake through root can be considered an important cause of variation in seedling growth performance of kidney bean. Some researchers had been demonstrated the relationship of different soil characters with the performance of plant growth (Bonanomi and Mazzoleni, 2005; Aziz et al., 2008).

The result of the present studies showed that the seedlings of kidney bean plants grown in polluted soil at T5 (100% soil contaminated) were considerably smaller in root, shoot and total seedling height and leaf area than those treated with less polluted soil T2, T3 and T4 respectively. Growth in terms of seedling length and root length of *P. vulgaris* were higher in T1 soil treatment. The above studies suggest that the variation in seedling growth performance of kidney bean seedling depend on the physical and chemical nature of soil used for treatment. The response of decrease in root growth of kidney bean to polluted soil treatment is of particular importance because it affects subsequent plant growth and ability to withstand environmental stresses. The treatment of different concentration of polluted soil type highly affected biomass production of kidney bean seedlings. In an investigation, the exposure of different types of abiotic and biotic stresses adversely affected the productivity of *Vigna mungo* (Kundu et al., 2011). Accumulation of toxic pollutants in soil imposes a major environmental threat to soil quality and limit crop yield. The depressive effect of polluted soil stress (T2-T5) treatments on dry weight of kidney bean seedlings could be related to the decline in root, shoot and seedling growth. The lowest seedling dry weight of kidney bean was observed in the T4 and T5 treatment of soil and indicating the strong influence of soil characteristics of the studied areas.

4. CONCLUSION

An intense industrial, anthropogenic activities and dumping of waste in Lyari River has polluted the soil. The accumulation of toxic chemical and pollutants could be responsible for changing the edaphic characteristics of the soil collected from Lyari River and influenced on seedling growth of kidney bean. It is evident from our results that the treatment of highly polluted soil (T5) proved to be highly responsive and sensitive for the seedling growth of *P. vulgaris* and could be used as indicator of soil quality. It was concluded that the seedling growth performance of *P. vulgaris* was poor with the increase in polluted soil treatment T2-T5 as compared to control soil treatment. The other discouraged factors were the low seedling tolerance and vigor indices of *P. vulgaris* due to soil pollution.

Highlights

- The significance of soil pollution impact on germination and seedling growth performance of *P. vulgaris* is addressed.
- A comparison was made between the effects of polluted and non-polluted soil impact on seedling growth performance of *P. vulgaris*.
- The treatment of polluted soil led to decreased seedling growth and seedling dry weight of *P. vulgaris*.
- The percentage of low seedling vigor and seedling tolerance index was found linked with the increase in concentration of polluted soil treatment.
- The treatment of different concentration of polluted soil to the seedlings of *P. vulgaris* could be served as a good soil pollution indicator.

Author's contribution

Muhammad Zafar Iqbal designed and supervised the experiment. Muhammad Hamza Khan performed the experiment and recorded the experimental data. Muhammad Shafiq prepared and draft the manuscript and surveyed the literature. All authors read and approved the final version.

Informed consent

Not applicable.

Ethical approval

Not applicable.

Conflicts of interests

The authors declare that there are no conflicts of interests.

Funding

The study has not received any external funding.

Data and materials availability

All data associated with this study are present in the paper.

REFERENCES AND NOTES

1. Al-Dulaimi RI, Ismail N, Ibrahim MH. The effect of industrial wastewater in seed growth rate: A Review. Int J Sci Res Publ 2012; 2(3):1-4.
2. Aziz EE, Hendawi ST, Din EE, Omer EA. Effect of soil type and irrigation interval on Plant growth, essential oil yield and constituents of *Thymus vulgaris* plant. Am-Eurasian J Agric Environ Sci 2008; 4(4):443-450.
3. Bewly JD, Black BM. Germination of seeds: In: Physiology and biochemistry of seed germination. Ed. AA Khan, Springer Verlag, New York 1982; 40-80.
4. Biggelaar CD, Lal R, Wiebe K, Eswaran H, Breneman V, Reich P. The Global impact of soil erosion on productivity: II: Effects on crop yields and production over time. Adv Agron 2003; 81 :49-95.
5. Bonanomi G, Mazzoleni S. Soil history affects plant growth and competitive ability in herbaceous species. Community Ecol 2005; 6(1):23–28.
6. Cachada A, Rocha S, Durate C. Chapter 1. Soil Pollution. An introduction to main issue. Elsevier, Academic Press 2018; 1-28.

7. Celmeli T, Sari H, Canci H, Sari D, Adak A, Eker T, Toker C. The nutritional content of common bean (*Phaseolus vulgaris* L.) landraces in comparison to modern varieties. Agron 2018; 8 (9):166. doi: 10.3390/agronomy8090166
8. Das DK, Prakash NS, Bhalla-Sarin N. An efficient regeneration system of black gram (*Vigna mungo* L.) through organogenesis. Plant Sci J 1998; 134:199–206.
9. Faluyi MA. Investigation on seedling vigor in Cashew (*Anacardium occidentale* L.). Plant Breed 1986; 97(3):237-245. doi: 10.1111/j.1439-0523.1986.tb01059.x
10. FAO. FAO Food and Agriculture Organization of the United Nations. Banco de dados online FAOSTAT 2019. http://faosta t.fao.org/ (22 Aug 2021).
11. Haghnazar H, Belmont P, Johannesson KH, Aghayani E, Mehraein M. Human-induced pollution and toxicity of river sediment by potentially toxic elements (PTEs) and accumulation in a paddy soil-rice system: A comprehensive watershed-scale assessment. Chemosphere 2023; 311(Part 1): 136842. doi: 10.1016/j.chemosphere.2022.136842
12. Justino LF, Júnior JA, Battisti R, Heinemann AB, Leite CV, Evangelista AWP, Casaroli D. Assessment of economic returns by using a central pivot system to irrigate common beans during the rain fed season in Central Brazil. Agric Water Manag 2019; 224:105749. doi: 10.1016/j.agwat.2019.105 749
13. Kundu S, Chakraborty D, Amita P. Proteomic analysis of salicylic acid induced resistance to Mung bean Yellow Mosaic India Virus in *Vigna mungo.* J Proteom 2011; 74(3):337-349.
14. Li X, Li L, Zhou Z, Li T, An J, Zhang S, Xu X, Pu Y, Wang G, Jia Y, Liu X, Li Y. Soil potentially toxic element pollution at different urbanization intensities: Quantitative source apportionment and source-oriented health risk assessment. Ecotoxicol Environ Saf 2023; 251:114550. doi: 10.1016/j.ecoen v.2023.114550
15. Martonas J. The effect of soil types on plants. http://www.ehow.com/facts 5880392 effect-soil-types-plants. html. Visited on 19-07-2012.
16. Oliver MA, Gregory PJ. Soil, food security and human health: A review. Eur J Soil Sci 2015; 66:257-276. doi: 10.1111/ejss.1221 6
17. Oyedeji A, Adebiyi A, Omotoyinbo M, Ogunkunle C. Effect of crude oil contaminated soil on germination and growth performance of *Abelmoschus esculentus* L. Moench—A Widely Cultivated Vegetable Crop in Nigeria. Am J Plant Sci 2012; 3 (10):1451-1454. doi: 10.4236/ajps.2012.310174
18. Rady MM, Ahmed SE, Selem E, Ahmed AA, Mohsen, Safaa MAI, Arnaout, El-Sappah AH, El-Tarabily KA, Desoky ESM. *Spirulina platensis* extract improves the production and defenses of the common bean grown in a heavy metals-contaminated saline soil. J Environ Sci 2023; 129:240-257. doi: 10.1016/j.jes.2022.09.011
19. Raimi MO, Iyingiala AA, Sawyerr OH, Saliu AO, Ebuete AW, Emberru RE, Sanchez ND, Osungbemiro WB. Leaving No One Behind: Impact of Soil Pollution on Biodiversity in the Global South: A Global Call for Action, Springer, Singapore 2022; 205-237. doi: 10.1007/978-981-19-3326-4_8
20. Rodríguez-Eugenio N, McLaughlin M, Pennock D, Bowen HJM. Soil pollution: A hidden reality. Educ. Chem, FAO, Roma 2018. doi: 10.5124/jkma.1998.41.10.1032
21. Shi B, Meng J, Wang T, Li Q, Zhang Q, Su G. The main strategies for soil pollution apportionment: A review of the numerical methods. J Environ Sci 2022. doi: 10.1016/j.jes.2022. 09.027
22. Taati A, Salehi MH, Mohammadi J, Mohajer R, Díez S. Pollution assessment and spatial distribution of trace elements in soils of Arak industrial area, Iran: Implications for human health. Environ Res 2020; 187:109577. doi: 10.1016/j.envres.202 0.109577
23. Tsegay BA, Gebreslassie B. The effect of salinity (NaCl) on germination and seedling growth of *Lathyrus sativus* and *Pisum sativus* var. abyssinicum. Afr J Plant Sci 2014; 8(5):225-2 31.
24. Vázquez-Arias A, Martín-Peinado FJ, Parviainen A. Effect of parent material and atmospheric deposition on the potential pollution of urban soils close to mining areas. J Geochem Explor 2022; 244:107131. doi: 10.1016/j.gexplo.2022.107131
25. Vega AS, Arce G, Rivera JI, Acevedo SE, Reyes-Paecke S, Bonilla CA, Pastén P. A comparative study of soil metal concentrations in Chilean urban parks using four pollution indexes. Appl Geochem 2022; 141:105230. doi: 10.1016/j.apge ochem.2022.105230
26. Wu G, Miao Z, Shao S, Jiang K, Geng Y, Li D, Liu H. Evaluating the construction efficiencies of urban wastewater transportation and treatment capacity: Evidence from 70 megacities in China. Resour Conserv Recycl 2018; 128:373–38 1. doi: 10. 1016/jresconrec.2016.08.020
27. Wu Y, Li X, Yu L, Wang T, Wang J, Liu T. Review of soil heavy metal pollution in China: Spatial distribution, primary sources, and remediation alternatives. Resour Conserv Recycl 2022; 181:106261. doi: 10.1016/j.resconrec.2022.106261

28. Yang L, Meng F, Ma C, Hou D. Elucidating the spatial determinants of heavy metals pollution in different agricultural soils using geographically weighted regression. Sci Total Environ 2022; 853:158628. doi: 10.1016/j.scitotenv.202 2.158628
29. Yuan X, Xue N, Han Z. A meta-analysis of heavy metals pollution in farmland and urban soils in China over the past 20 years. J Environ Sci 2021; 101:217-226. doi: 10.1016/j.jes.202 0.08.013
30. Zeng J, Tabelin CB, Gao W, Tang L, Luo X, Ke W, Jiang J, Xue S. Heterogeneous distributions of heavy metals in the soil-ground water system empowers the knowledge of the pollution migration at a smelting site. J Chem Eng 2023; 454 (2):140307. doi: 10.1016/j.cej.2022.140307
31. Zwolak A, Sarzyńska M, Szpyrka E, Stawarczyk K. Sources of soil pollution by heavy metals and their accumulation in vegetables: A review. Wat Air Soil Pollut 2019. doi: 10.1007/s 11270-019-4221-y