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Assessment of growth, and ion uptake of plant species, *Conocarpus erectus* and *Dodonaea viscosa*, on industrial solid waste

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Abstract

Present study assessed the growth of two plant species and ion uptake by them grown on different proportion of industrial solid waste and garden soil. The industrial waste having high concentration of chemicals were used with garden soil at different proportion i.e. 0% (T0), 5% (T1), 10% (T2), 15% (T3) and 20% (T4). Two species namely *Conocarpus erectus (alien plant) and Dodonaea viscosa* (indigenous) were used as test plants in pot study. Different parameters including growth, physiology, and anatomy of plants and concentration of cations (Na^+, K^+, Ca^{2+}, and Mg^{2+}) in the plant shoot and root were measured at different time duration (initial, 1st, 2nd, 3rd and 4th month). The key objective of the study was to use these plants to establish their plantations on the barren lands where industrial solid wastes were being disposed of. *C. erectus* showed better growth than *D. viscosa,* as well as more uptake of ions. A significant increase in plant growth was observed in fourth month in T1, where plant height reached 24.5% and 46% for *C. erectus* and *D. viscosa*, respectively. At harvest, in *C. erectus*, no significant difference in the fresh (65–78 g) and dry weight (24–30 g) of the shoot was observed across treatments compared to the control. In *D. viscosa*, at the time of harvest, the fresh and dry weights of the root and shoot showed a strong, significantly decreasing pattern across T1, T2, and T3, leading to the death of the plant at T3 and T4. Further, optimum ratio of waste soil to garden soil was found as 10:90 and 20:80 to establish the plantations of *D. viscosa* and *C. erectus*, respectively in areas where such solid waste from industries are disposed. Findings can be used for the restoration of such solid waste for the sustainable management of industrial areas and their associated ecosystems.

Keywords Ecosystem restoration, Environmental management, Industrial ecology, Pollution remediation, Waste management

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Introduction

Industrial waste is usually referred to the kind of waste produced by industrial activities and having less or no use in manufacturing process. Examples of such wastes are wastewater and soil [1]. These wastes are produced from industrial processes, different power stations, factories, industrial plants, mining industries, chemical industries and manufacturing industries. Industrial waste contains toxic chemicals and heavy metals that deteriorate the soil quality and eventually affect the plants' growth [2–5]. In 2008, the European Union agreed on a regulation, which was part of the European Union Circular Economy Package that eased the use of waste-based fertilizers in the EU agricultural market [6, 7]. Approximately one-third of sludge and industrial waste is recycled in agriculture, and in Europe, 50% of sludge waste is used in agricultural soil as fertilizer [8]. Major European countries are following and enforcing guidelines of closed-loop system for the use of waste as agricultural fertilizer as issued by EU directives [8, 9].

Waste management is becoming increasingly challenging in developing Asian countries, particularly in Pakistan. There is a wide range of waste generation rates across regions and income levels, with Gujranwala generating 0.33 to 0.46 kg/capita/day, while Asian developing countries produce 0.4–1.62 kg/capita/day [10]. The production of industrial waste in Pakistan is estimated at 100,000 tons/day nationally and 10,000 tons/day in Lahore [11]. There is 0.667 kg of waste generated per bed/day in Gujranwala hospitals, with 25.8% hazardous infectious waste and open dumping [10, 11] are common waste management challenges. To address the environmental and health impacts of increasing waste generation in developing Asian countries, sustainable waste management practices are necessary, including composting, recycling and recovery.

Industrial waste induces stress because industrial waste mostly occurs in arid and semi-arid areas of the world. Ions that cause industrial waste stress vary in their concentration and depend upon several factors, such as climate and soil chemistry. The major elements that are present in the form of salts are Na^+, Mg^{2+}, Ca^{+2}, K^{+1}, etc. The major cause of industrial waste stress in developing countries is poor drainage systems [12]. Globally, 21% of the area affected by soil industrial waste stress is irrigated land (about 20% of the world is affected). About 17% of the area of Pakistan was saline, and 1% was partially saline; 82% of this was affected by the three drainage projects set up in Pakistan [13]. The investigated study concludes that soil salinity is mainly caused by industrial waste [14]. In the future, these saline conditions may increase due to population pressure, which has brought irrigated land into salinization hazards. Here, some other problems are also developed due to industrial waste stress, such as increased soil erosion and desertification of agricultural land [15].

In Pakistan, many chemical industries generate huge amount of waste every year. Similar is the case of the selected chemical industry for the present study, located in Sheikhupura near Kala Sha Kaku, which generates solid waste that contains many toxic chemicals. This industry is manufacturing inorganic chemicals such as caustic soda, chlorine gas, HCl, and H_2SO_4. The pesticide products of the industry are bentonite clay, zinc sulphate, and sodium hypochlorite. The waste effluents include extra HCL, waste lime, and brine impurities, which are deposited outside the industry in Nalla Degh, near GT Road [16]. The study conducted in Canada on solid waste disposal by landfilling showed that ions and other chemicals change the soil chemistry. The nearby area where solid waste is deposited has a different soil chemistry as compared to normal soil and has a significant effect on the plants' growth [17, 18].

Industrial pollutants from the selected chemical industry pose environmental threat to groundwater resources, which may affect the process of leaching and consequently affect soil productivity and agricultural crops growth (e.g. height, biomass) and quality of the produce [16]. It can also be a potential threat to the food web due to the high number of ions (sodium and calcium), poisonous chemicals and toxic metals.

Halophytes such as *Salicorinia europaeal* can tolerate up to 1000 mM salt concentrations. These plants have adaptive mechanisms to store Na^+ and other salts, mainly in their organ tissues and subcellular structures. It is found that ionic accumulation in different plant parts occurs when grown in the industrial solid waste, and by adding a proportion of compost. The overall status of crop production can be enhanced by adding some organic amendments into the soil. It not only reduces the negative impacts of industrial waste on the environment but also promotes sustainable agriculture practices [19–21]. The wasteland can be converted into cultivated land by growing salt-tolerant plant species in salt-affected soil. As plant nutrients such as nitrogen, phosphorus, and potassium, as well as other micro- and macronutrients are present in sludge waste and industrial sewage, it may be used as conventional fertilizer in the production of economically important crops [22, 23].

The present study explores the impact of solid waste from the selected chemical industry on the agronomic, physiological and biochemical parameters of *D. viscosa* and *C. erectus*. It enhances the understanding of how the waste of the chemical industry affects the plant growth of selected species and ionic uptake in different organs of the target plants. The restoration of sites of industrial solid wastes using appropriate perennial plants is required to enhance the carbon and pollutant sinks in such industrial areas. Thus, the enhancement of green cover is required to control industrial pollution, which requires investigations into the selection of suitable plants for such habitats. This study was primarily concerned with investigating the growth of plants exposed to solid wastes at various levels (1); investigating the accumulation of Na + and K + in above-ground and below-ground parts (2); and examining the physiological and biochemical features of the plants (3). Tree species such as *C. erectus* and *D. viscosa* were used to enhance the vegetation cover to increase pollutants' sink by adding greenery and reducing solid waste in a sustainable manner. As a result, the number of pollutants released into the atmosphere and waterways would be reduced. Furthermore, these plants would help to increase the biodiversity of the garden and provide food for local wildlife.

Plant species

Conocarpus erectus is a tree species that belongs to the Combretaceae family and is usually found at shorelines in tropical and subtropical regions around the world. These are shrubs (multiple trunked) or trees growing 1–20 m tall. These are also named "cone"-fruit"-bearing plants [24]. *Dodonaea viscosa* was the selected plant species for the experiment, commonly known as Sanatha in Pakistan. A shrub or small tree that has height about 5 m. Leaves are clustered, simple, spiral, alternate, stout, narrowly elliptic to oblanceolate, and swollen at the base. Fruit and seed are membranous [25].

Materials and methods

Study site and experimental setup

The experimental setup was set up in the Botanical Garden, Government College University Lahore (GCUL) under natural environmental conditions. The garden soil was collected from the Botanical Garden and industrial waste/ soil was collected form the chemical industry (Fig. 1). The different proportions of waste and garden soil were used in the pot study for growing the selected plant species, as given Table 1. Chemical composition of industrial and garden soil is given in Table 2. Twenty pots were filled with the prepared mixtures (treatments) of garden soil and solid waste using the plastic bags, as shown in Fig. 2. After two days, the 0.9-inch-high plants were selected and transferred into the pots, and the plants were available in the nursery of the botanical garden. Four replicates were used for every treatment, and 24 plants were used for this purpose. The number of leaves was counted, and height was measured with a scale. After the transfer of plants into pots, the pots were labelled with treatments.

Plant growth parameters

Monitoring of plant height and the number of leaves was carried out on regular basis. The plants were harvested after four months. Soil was removed from the pots and roots were carefully separated. Weight of shoots and roots was measured using balance. The length of the root and shoot was also measured. The leaf area of the leaves was calculated using the graph method. The area was calculated in cm^2. All the samples of the root and shoot from all treatments were placed in an oven (Memmert, Germany) at 70 °C for 72 h. The samples were weighted to assess the dry mass. Garden soil has a higher pH than red and white soil. Red soil and garden soil have a lower amount of Ca^{+2} than white soil. Similarly, phosphorus, Na +, and K + are less in garden and white soil than in red soil.

Photosynthetic and gaseous exchange parameters

At the flowering stage, Infrared Gas Analyzer (IRGA), portable photosynthetic system (ADC Bioscientific Ltd.), was used on sunny day to measure chlorophyll content, stomatal density, and maximum rate of transpiration and leaf gas exchange [26].

Determination of Na^+ and K^+

The selected samples (seed, fruit leaf, stem, and root) from each treatment of each of the pots were dried in the oven at 70 °C for 72 h. Samples of leaves, stems, seeds, and roots were converted into ash in a muffle furnace (Size 2). The ash was dissolved in 30 mL of 0.01 N nitric acid. The solution was then filtered and poured into the flask, and the volume was raised to 100 mL. The filtrate was then transferred to the sample bottles. A Spectro Lab Model S20 Automatic Flame Photometer was used to analyze the Na^+ and K^+ accumulation in the sample [27, 28].

Estimation of Na^+, K^+, Ca^2, and Mg^{2+} in soil

Gram air-dried and sieved soil was taken and dissolved in 100 mL of distilled water, stirred for 5 min, and then left for one hour. After one hour, stirred again, and filtered with Whitman's filter paper no. 2. Filtrates of every pot of soil were used for chemical estimation. Na^{+1} and K^{+1} was estimated with the help of a flame photometer (model S20), and Ca^{2+} and Mg^{2+} were estimated from absorption spectroscopy (thermofisher ice 3000) [29]. The values were recorded on Sigma Plot Version 14.0.

Statistical analysis

The experimental results obtained were expressed in terms of means and standard error. A one-way ANOVA

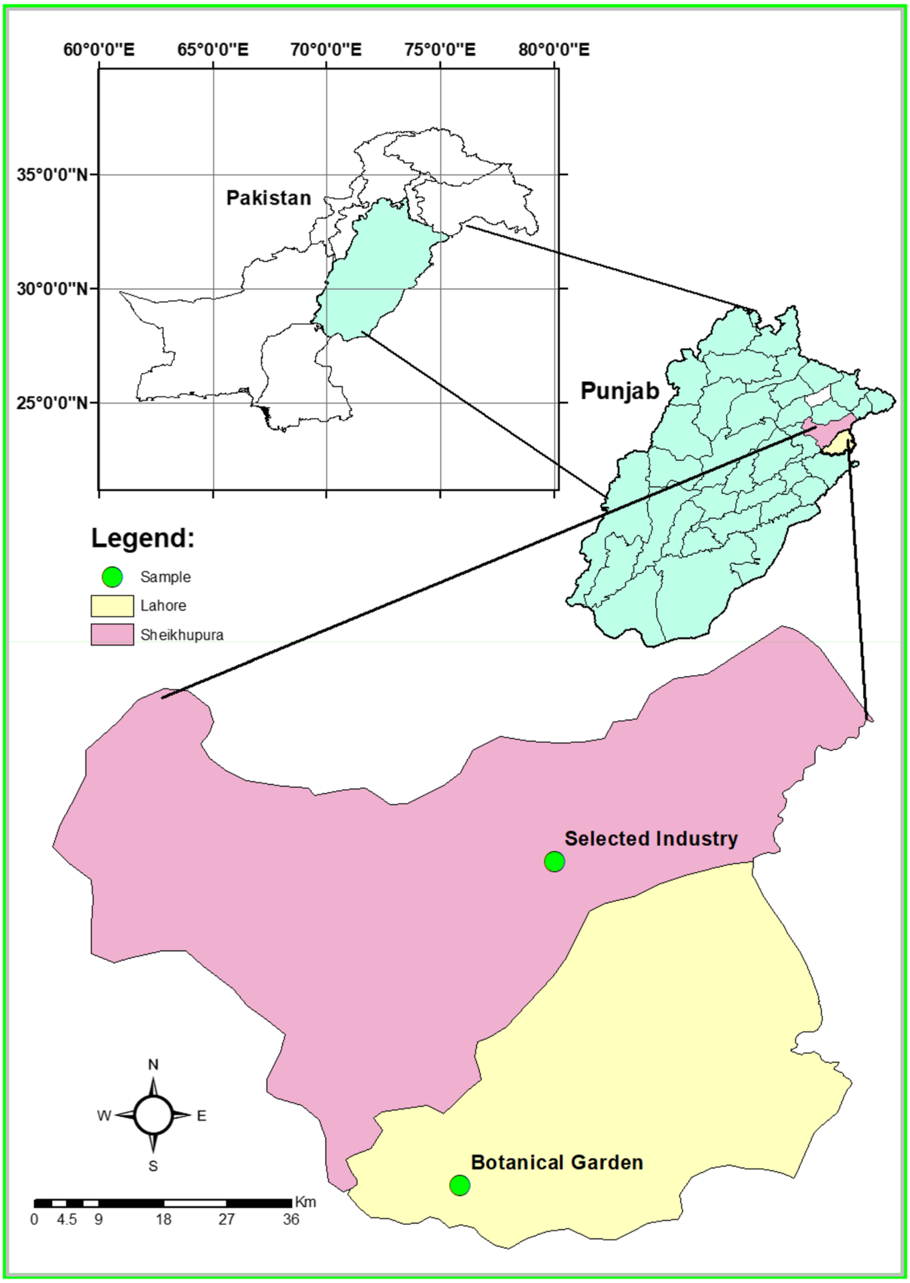


Fig. 1 Study area map showing location of the selected industry, source of industrial waste, and botanical garden, source of garden soil and experimental site

(DMRT) was used to test the significance and comparison among treatments. Correlations, statistical analyses, and graphics were carried out using the software Sigma Plot v 14.5 (Systat Software, San Jose, CA). Principal Component Analysis (PCA) was conducted to find the trends in the data set of different plant parameters. PCA being a dimensionality reducing technique is adopted to reduce number of parameters of a large data set.

Results

Effect of industrial waste stress on growth

The height of the plants was monitored each month (month 1 to 4). In *C. erectus*, there was a non-significant

Table 1 Percentage of industrial chemical waste and garden soil

Treatments	Industrial waste (%)	Garden soil (%)	Soil quantity/ pot (Kg)	Waste quantity/ pot (Kg)
To	0	100	8.0	0.0
T1	5	95	7.6	0.4
T2	10	90	7.2	0.8
T3	15	85	6.8	1.2
T4	20	80	6.4	1.6

difference ($P > 0.05$) relative to control, followed by growth across all treatments except for T0 and T1, which showed a significant increasing trend every month with a range of 9 to 25 inches, but T2, T3, and T4 showed a non-significant increasing growth pattern ($P > 0.05$). Figure 3A (a-e). In *D. viscosa*, a significant increasing growth trend was observed in the 3rd and 4th months in T0 ($P < 0.05$) relative to control. While in T1, a significant increase in plant height was observed in month 4 only, followed by a strong and significant change in growth across T2 plants, where plant height decreased rapidly from months 2 to 4. In T3, plants resisted for 2 months, with a significant decline in growth leading to wilting in the 3rd month. Treatment T4 was strong enough for the plant species, and hence, the plant died at an early stage of vegetation as shown in Fig. 3B (a-e). There is increase in plant height in case of *C. erectus*, 187% (T1), 257% (T2) and 439% (T3). However, in case of D. viscosa, plant height decreased by 21% (T1) and 79% (T2).

Effect of industrial waste stress on leaf number

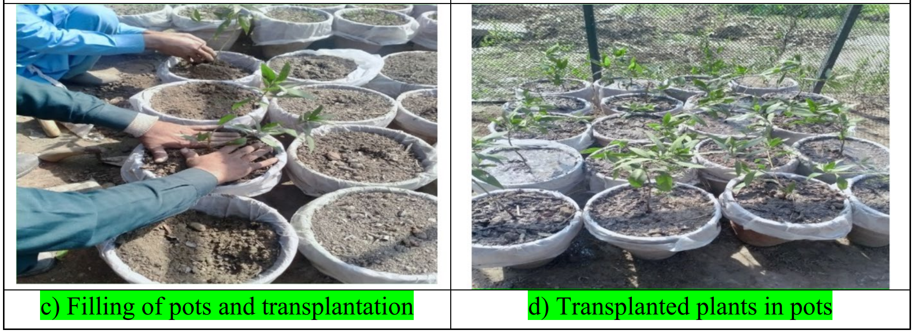
The leaf number was also counted each month during the study time. In *C. erectus*, there was a non-significant difference ($P > 0.05$) relative to control every

Table 2 Chemical analysis of industrial waste and garden soil

Type of soil	pH	Organic matter (%)	Ca^{+2} (ppm)	Na^{+} (ppm)	K^{+} (ppm)	P (ppm)
Industrial waste (red soil)	6.00	0.112	26	170	6	3.0
Industrial waste (white soil)	7.51	0.027	280	13	0	3.5
Garden soil	7.84	1.0	10	10	2.54	2.25

a) Industrial solid waste

b) Prepared industrial waste/ soil



c) Filling of pots and transplantation

d) Transplanted plants in pots

Fig. 2 Pictures taken at different stages of the pot study: industrial solid waste (**a**), prepared industrial soil (**b**), filling of pots and transplantation and transplanted plants in pots

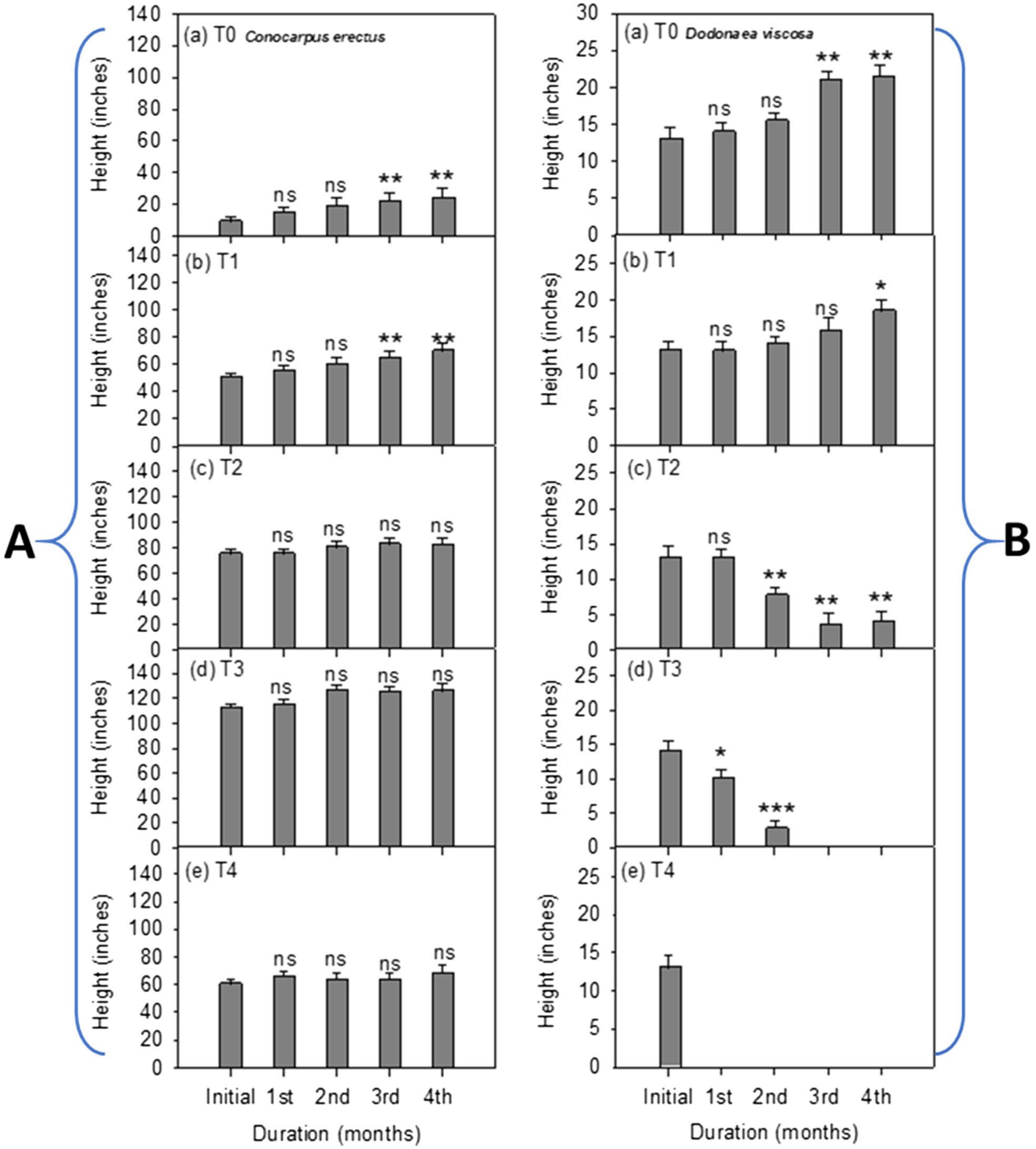


Fig. 3 Means (± SE) of plant height in *C. erectus* **A** (a-e); and *D. viscosa* **B** (a-e); for different treatments (T0 to T4) Where ns represents non-significant difference, *** indicate $P < 0.0001$, ** $P < 0.001$ and * $P < 0.05$

month, with an increasing growth trend in T1 and T2, followed by a decrease in growth at T3 and T4, as shown in Fig. 4A (a-e). In *D. viscosa*, a significant increasing growth trend was observed in the 2nd, 3rd, and 4th months in T0, T1, and T2 ($P < 0.05$) relative to the initial vegetative phase. While in T3, a strong

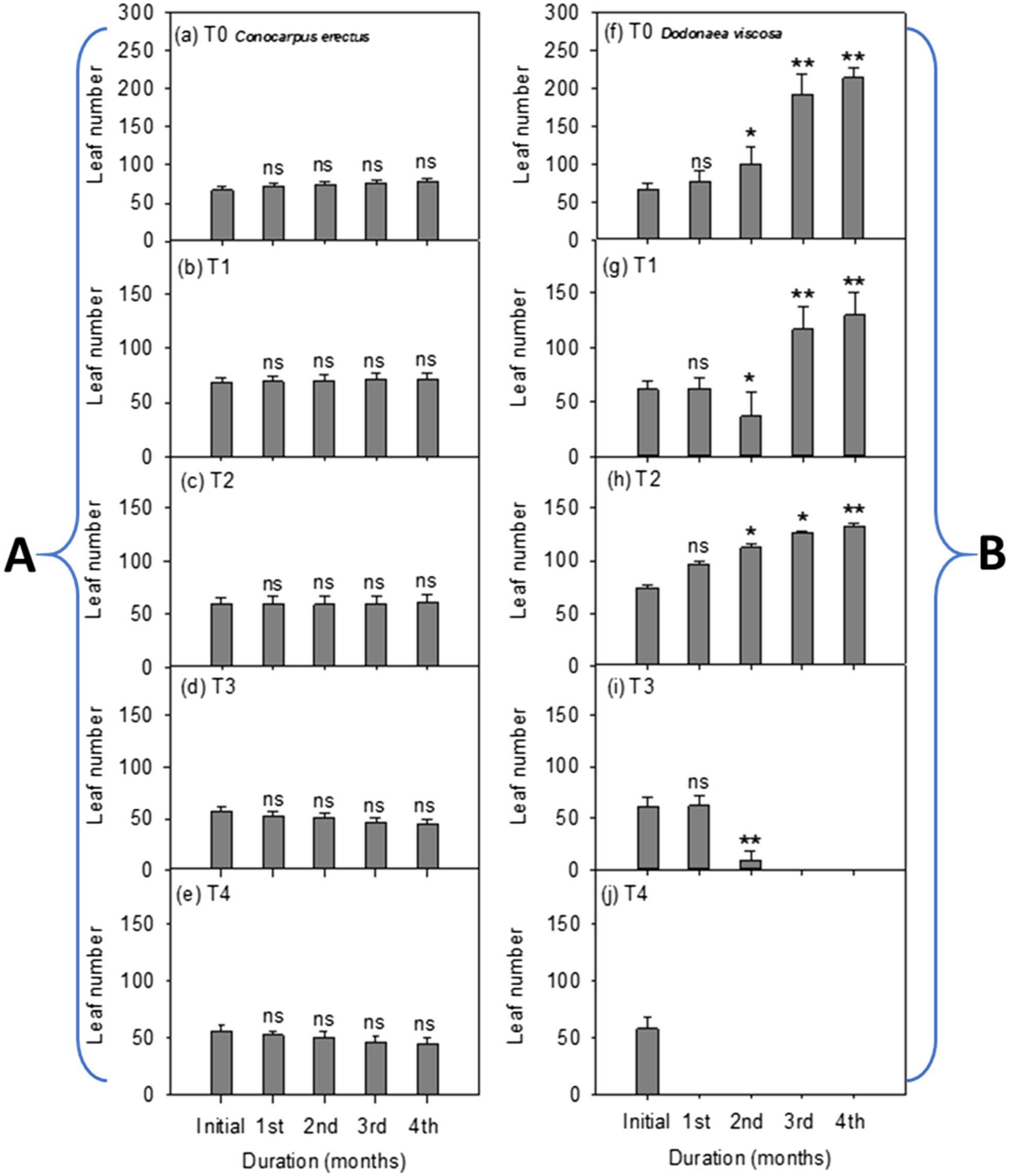


Fig. 4 Means (± SE) of leaf number in *C. erectus* **A** (a-e); and *D. viscosa* **B** (f-j); for different treatments (T0 to T4) Where ns represents non-significant difference, *** indicate $P < 0.0001$, ** $P < 0.001$ and * $P < 0.05$

and significant change in leaf number was observed. Leaf number decreased rapidly in the 2nd month and ultimately wilted in the 3rd month. Treatment T4 was strong enough for the plant species, and hence, the plant died at an early stage of vegetation, as shown in Fig. 4B (f-j).

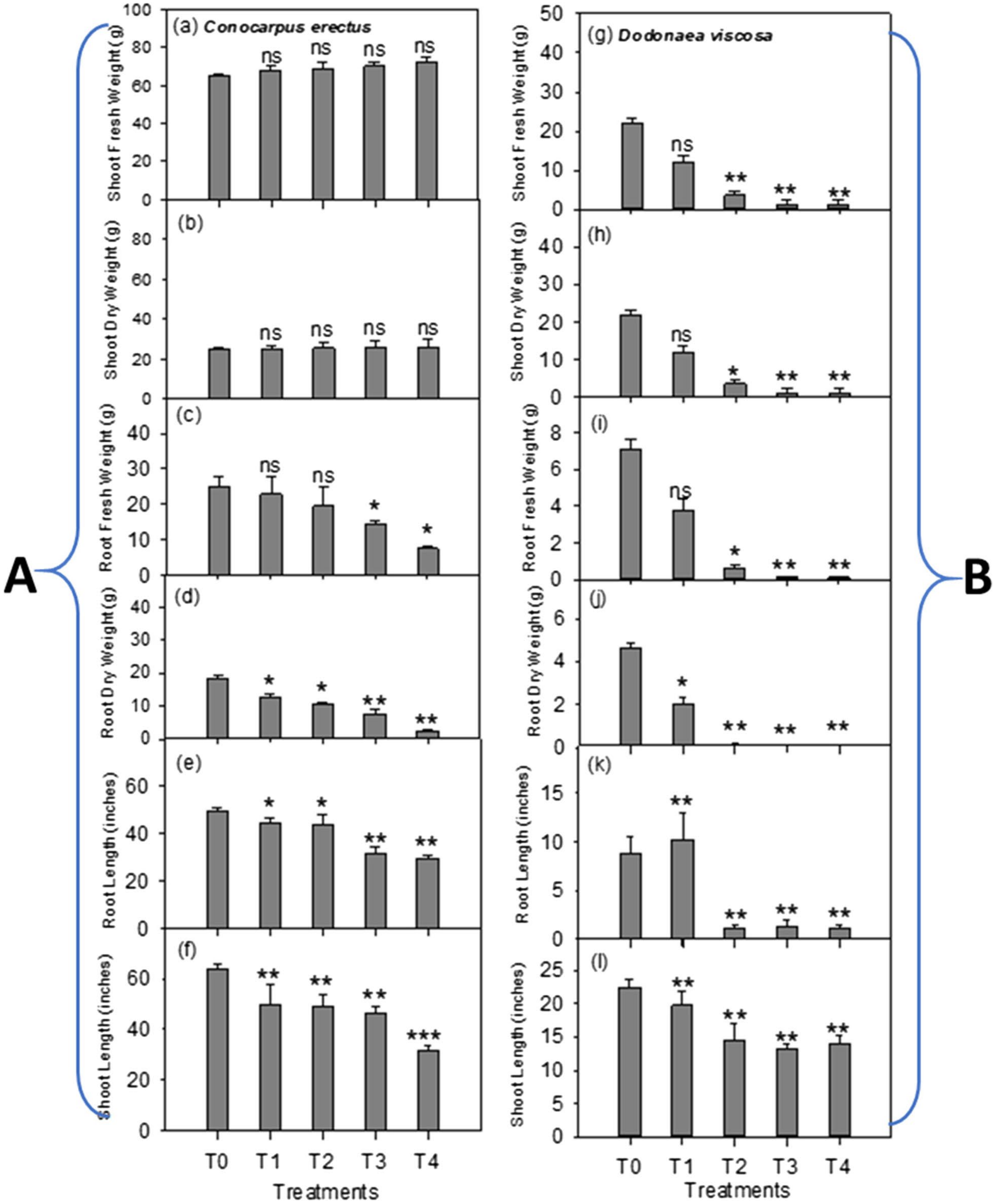


Fig. 5 Mean harvest biomass of *C. erectus* and *D. viscosa* respectively, mean fresh and dry weight of shoot, fresh and dry eight of roots, root length as well as shoot length respectively **A** (a- f). the similar parameters were observed in the case of *D. viscosa* **B** (g-l) for each treatment (from T0 to T4). Bars and mean ± SE. Where ns indicates non-significance difference, *** indicate $P < 0.0001$, ** $P < 0.001$ and * $P < 0.05$

Effect of industrial waste stress at harvest

At harvesting stage, in *C. erectus*, no significant difference in the fresh and dry weight of the shoot was observed across all the treatments compared to the control Fig. 5A (a, b). The fresh weight of the root under T3 and T4 decreased significantly compared to the control, while the root dry weight under T1 to T4 was significantly lower than for T0 Fig. 5A (c-d). Similarly, for root and shoot length, a strong, significantly decreasing trend was observed across all treatments, i.e., from T1 to T4, compared to the control.

In *D. viscosa*, at the time of harvest, the fresh and dry weights of the root and shoot showed a strong, significantly decreasing pattern across T1, T2, and T3, leading to the death of the plant at T3 and T4, where data shows values in points as in Fig. 5B (g-j). The root length decreased sharply at T2, T3, and T4, while shoot length significantly decreased across all treatments compared to the control, as shown in Fig. 5B (k-l).

Determination of accumulation of Na^+ and K^+

In *C. erectus*, a significant and positive relationship was observed between Na+and waste treatments in leaves (R^2=0.97**), stems (R^2=0.96*), and roots (R^2=0.96*) across all treatments. The relation between K+and treatments showed a significant and negative trend in roots (R^2=0.91**), while the slope for leaves (R^2=0.67*) and stem (R^2=0.95**) showed a positive relationship Fig. 6 (a, b).

In *D. viscosa*, a significant and positive relationship was observed between Na+and waste treatments in leaves (R^2=0.91*), stems (R^2=0.96*), and roots (R^2=0.94**) across all treatments. In T3 and T4, leaves died at harvest. The relation between K+and treatments showed a significant and negative trend in roots (R^2=0.89*), leaves (R^2=0.82*), and stems (R^2=0.91**) across all treatments except for T3 and T4 in leaves (Fig. 6c-d).

Determination of gas exchange

C. erectus plants in T2 to T4 showed a significantly decreasing rate of transpiration compared to T0, while

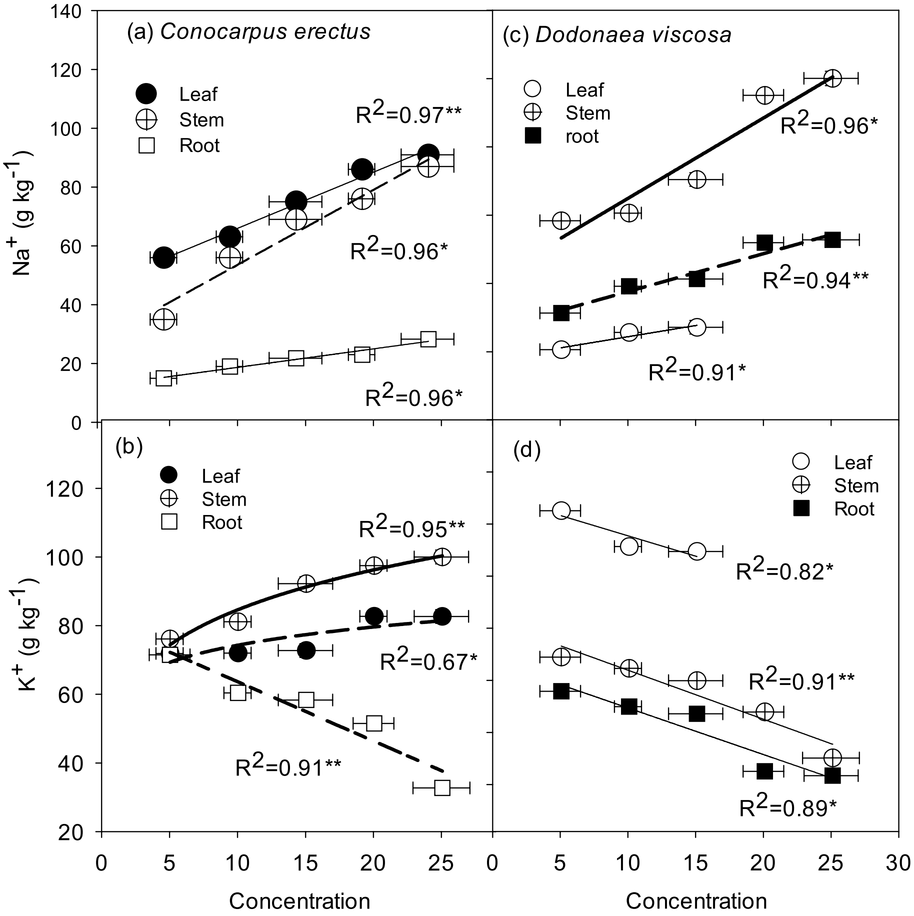


Fig. 6 Relationship between Na^+ (**a**, **b**), $K.^+$ (**c**, **d**), and Salt treatments of *C. erectus* and *D. viscosa* respectively across all treatments. Each symbol indicates the specific tissue of the particular organ. Where *indicate $P < 0.05$, ** $P < 0.01$

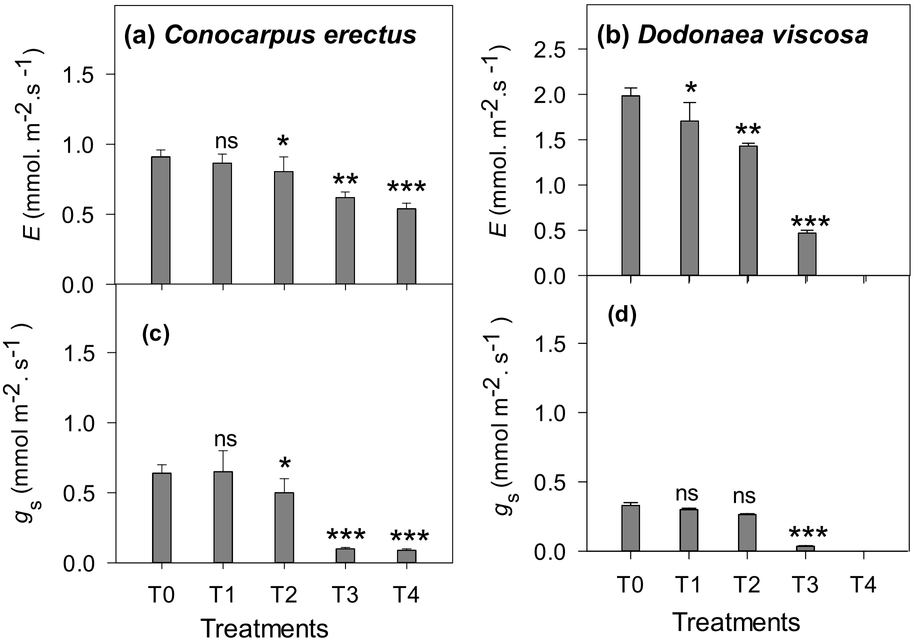


Fig. 7 Gas exchange of *C. erectus* and *D. viscosa* under different treatments. **a**, **b** Maximum rate of transpiration (E); (**c**, **d**) maximum stomatal conductance (g_s). Where ns indicate non-significant difference while *** indicate $P < 0.0001$, ** $P < 0.001$ and * $P < 0.05$

T1 showed a non-significant difference. In *D. viscosa*, the transpiration rate decreased significantly in T1, T2, and T3, while T4 leaves died, showing zero activity (Fig. 7a-b).

Similar is the case with the rate of stomatal conductance. In *C. erectus* plants, T2 to T4 showed a significantly decreasing pattern compared to T0, while T1 showed a non-significant difference. While in *D. viscosa*, the conductivity rate remained non-significant in T1 and T2 and decreased significantly in T3, while T4 leaves died, showing zero activity (Fig. 7c-d).

Foliar parameters

At harvest, the chlorophyll content in the leaves of *C. erectus* showed non-significant differences across all treatments except T4, which showed a significant, slight reduction from T0. Leaf area reduced significantly from T2, T3, and T4 when compared with T0, while T1 reduced non-significantly. Stomatal density showed a significant decrease across all treatments when compared with the control, as shown in Fig. 8 (c, f) respectively.

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Soil analysis

A significant positive relationship between soil nutrients and solid waste treatment was observed in *C. erectus* in such a way that Ca ($R^2 = 0.93^{***}$) and K ($R^2 = 0.81^{*}$) concentrations increased significantly with increasing waste concentration. The slope of Mg ($R^2 = 0.94^{***}$) was close to the x-axis across all the treatments, while the slope of Na ($R^2 = 0.79^{*}$) showed a significant negative trend, as shown in the Fig. 9a.

In *D. viscosa*, a significant positive relationship between soil nutrients and solid waste treatment was observed in such a way that Ca ($R^2 = 0.91^{*}$) and Na ($R^2 = 0.93^{**}$) concentrations increased significantly with increasing waste concentrations. The slopes of Mg (R2 = 0.80^{**}) and K ($R^2 = 0.81^{*}$) were close to the x-axis across all the treatments, showing a slight, significant negative trend, as shown in Fig. 9b.

PCA was conducted to find the trends in the data set of plant parameters (Fig. 9a, b). This divided the data into two major components/factors (Fig. 10). However, more than 99% variance was represented by only two components (PC1 & PC2) with Eigenvalues noted greater than one. Component matrix of PCA showed that most of the plant parameters belong to PC1 that explained 95.2% variation for *C. erectus* and 92.7% variation for *D. viscosa* of the total variation while a few plant parameters belong to PC2 that explained 4.7% variation in case of *C. erectus* and 6.9% variation in case of *D. viscosa* of the total variation.

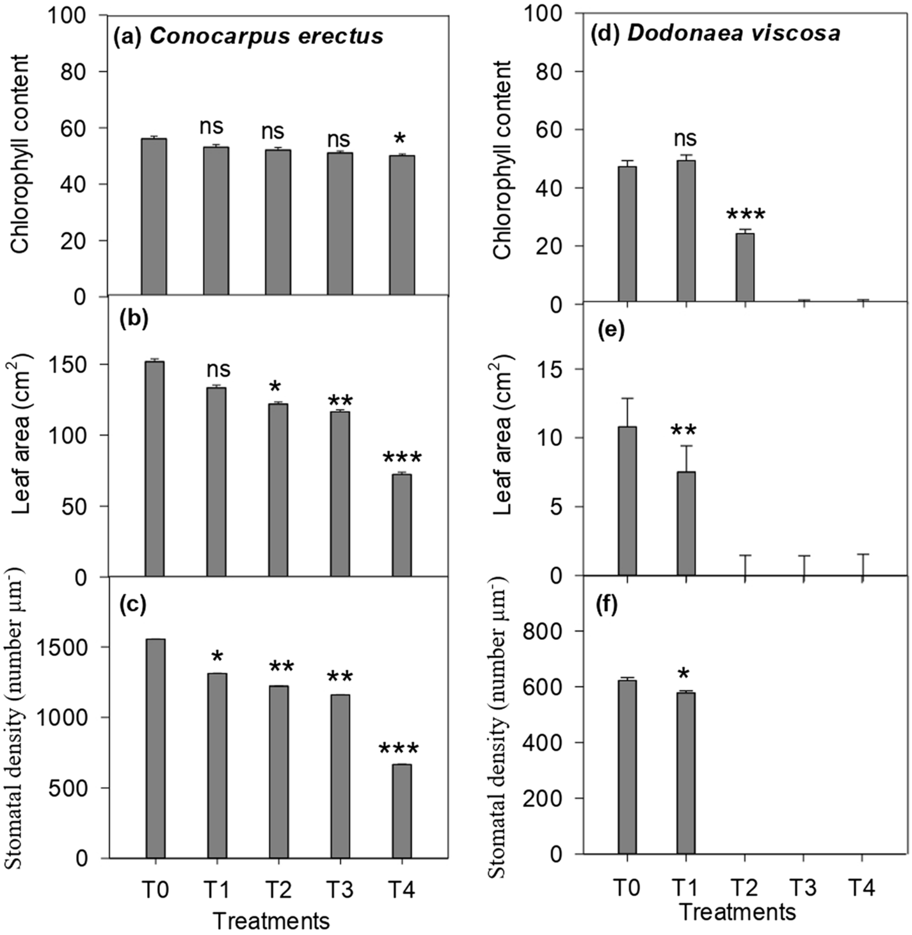

Fig. 8 Chlorophyll content (**a**, **d**); Leaf area (**b**, **e**); and Stomatal density (**c**, **f**) of *C. erectus* and *D. viscosa* respectively at harvest, for each treatment (from T0 to T4). Bars and mean ± SE. Where ns indicate non-significant difference while *** indicate $P < 0.0001$, ** $P < 0.001$ and * indicate $P < 0.05$

Discussion

The present study was carried out to find the effect of chemical industrial solid waste on some growth, physiological, and biochemical features of *C. erectus and D. viscosa*. These plant species have great medicinal importance because of their anti-ulcer and anti-inflammatory activities [24, 25]. It was found that solid waste affects plant growth, and plants could not survive at the toxic levels of waste, as shown in Figs. 3 and 4. Similar results were found in a study on cottonwood and eucalyptus trees [2]. The application of municipal solid waste compost (MSWC) and sewage sludge can enhance woody tree growth and yield [30]. If heavy metals are present in waste, it can negatively impact tree growth. Shah et al. (2011) found that cadmium and chromium exposure reduced growth and nutrient uptake in *Eucalyptus camaldulensis* [31]. Similarly, high wastewater concentrations from beef cattle slaughterhouses impaired eucalyptus seedling growth and increased mortality [32]. Trees can potentially bioaccumulate heavy metals, with higher concentrations found in roots and bark than in other tissues [30]. While waste amendments can improve tree productivity, careful management is necessary to avoid toxicity and ensure optimal growth, especially in low-fertility soils or arid regions [30]. It deteriorates the soil quality and causes reduced plant cultivation and production [33]. Chemical analysis of garden and industrial waste soil showed that the red soil of industrial waste has a high amount of Na^+ and K^+, as given in Table 2, which explains why the soil is highly saline. Growth parameters such as shoot height and the number of leaves initially showed a non-significant response toward the solid waste in both species, but after one month, they showed a significant difference with respect to the above growth parameters (Fig. 3), causing wilting in *D. viscosa* in later months [34]. This may be due to cytoplasmic toxicity because of the high Na concentration in red soil [35]. Stomatal density was affected by the waste in both species, which may be because of the insufficient osmotic adjustments leading to reduced net photosynthesis in

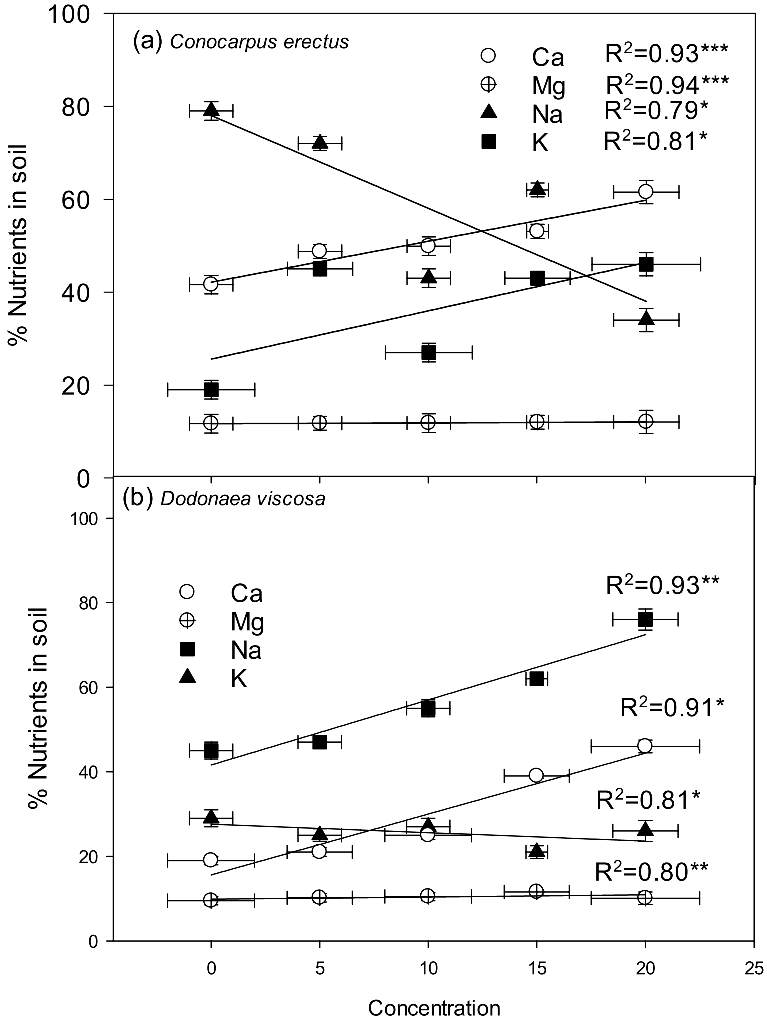

Fig. 9 Percentage nutrient s in soil (**a**) *C. erectus*, (**b**) *D. viscosa* respectively at harvest, for each treatment (from T0 to T4). Where *** indicate $P < 0.0001$, ** $P < 0.001$ and * indicate $P < 0.05$

the treatment of 10–15% of the waste. High concentrations of solid water showed a reduction in the growth and above-ground mass of *D. viscosa*. This reduction in growth and biomass occurred due to the change in soil fertility [36]. Leaf area and stomatal density showed no significant relation to the treatment of solid waste in the Ittehad Chemical Industry due to the non-survival of plants after 5% of the solid waste in *D. viscosa*.

Industrial waste stress increased Na concentration in leaf, shot, and root with a decrease in K concentration (Fig. 6) in *D. viscosa*, which might be due to ionic toxicity. In *C. erectus*, an increase in Na concentration in leaves and stems may be because of the salt accumulation capacity of halophytes [37], as a result of the high mineral nutrient concentration under slat stress observed in sunflower and maize crops [38]. Industrial waste stress, particularly salinity, significantly impacts plant nutrient dynamics. Studies on various crops show that increased NaCl concentrations lead to higher Na + accumulation in plant tissues, while K^+ levels decrease [39, 40]. This trend is observed in leaves, stems, and roots, with roots often accumulating the highest Na^+ concentrations. The Na^+/K^+ ratio increases under salt stress, affecting plant growth and yield. Different plant parts show varying tolerance to salinity, with younger leaves and reproductive structures generally maintaining better K^+/Na^+ ratios [40]. Salinity tolerance varies among species, with Helianthus annuus showing higher tolerance than Solanum lycopersicum. These findings highlight the complex interplay between Na^+ and K^+ in plants under salt stress and its implications for crop cultivation in saline environments.

The rate of stomatal conductance and transpiration decreased with the increase in solid waste. This reduction

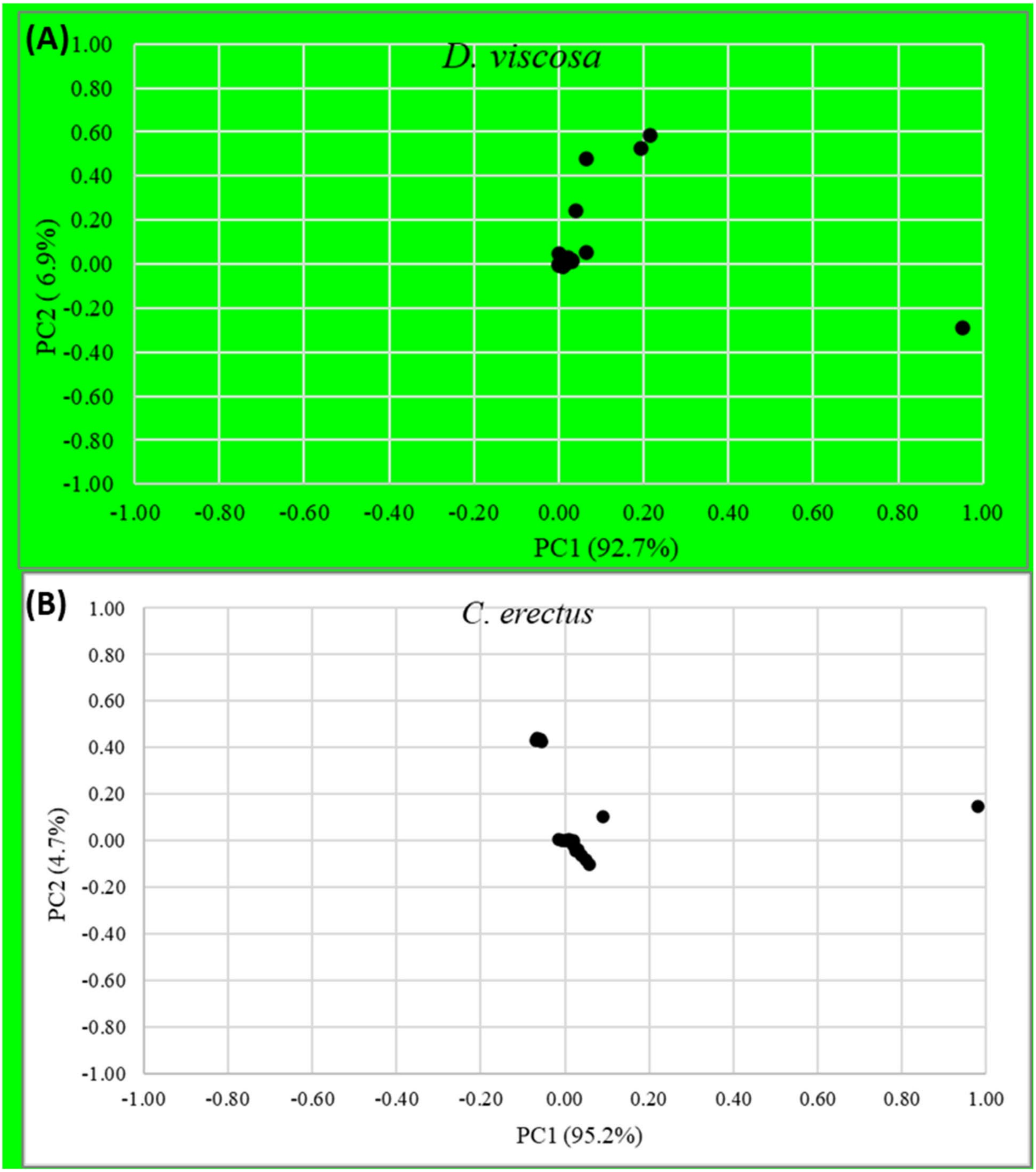

Fig. 10 Principal component analysis for variables of *D. viscosa* (**A**) and *C. erectus* (**B**)

of gas exchange parameters confirms that a high amount of solid waste disturbs the physiology of the plant, and this occurred due to the increases in Na^+ concentration, which disturb the osmotic protonation of leaves [41]. Another possible mechanism may include the deposition of Na under the cell wall of roots, which causes hindrance in the translocation of water. The water use efficiency was reduced in both species due to applied toxic waste, as plant growth faces initial free water movement through xylem [42].

According to other studies, the total chlorophyll content of plants increases initially, but prolonged exposure to solid waste limits the chlorophyll contents [43, 44], as the present study showed a non-significant difference in chlorophyll content with different treatments of solid waste. The results support the report, which states that an increase in Na^+ concentration in leaves reduces chlorophyll contents [45].

Analysis of soil Ca, mg, Na, and K concentrations revealed that Ca and K concentrations were high in the soil of *C. erectus*. This may be due to the fact that high Na accumulation in roots hinders K uptake from the soil through the xylem [46, 47]. Similarly, in *D. viscosa*, Na and Ca concentrations were high, which explains the wilting of plants at an early stage of vegetation. It may involve different mechanisms, such as excessive salt compartments and hindrances in osmotic adjustment. A key adaptive mechanism involves high K uptake, which was blocked by Na toxicity, and therefore growth was shunted at an early stage. Physiological effects of soil cations (Ca^{2+}, Mg^{2+}, K^+, and Na^+) are explored in the various studies. Lasthenia californica has differential ion uptake and tolerance among two edaphic races, suggesting that physiological traits have evolved in parallel. Luan et al. (2009) described the CBL-CIPK signaling network, which regulates K^+ and Na^+ transport in response to Ca^{2+} changes [48]. Under salt stress, elevated Ca^{2+} levels reduced Na^+ influx and improved K^+/Na^+ selectivity in cotton seedlings. Together, these studies emphasize the importance of cation balance in soil and plant tissues, as well as Ca^{2+}'s role in mitigating Na^+ toxicity and maintaining K^+ uptake. This highlights the importance of Ca^{2+}, as well as the need for further research in this area. Further research could help us understand the physiological and molecular mechanisms behind Ca^{2+} mediated regulation of cation transport.

Conclusion

A pot study was conducted to assess the growth and ion uptake of plant species grown on soils having different proportions of industrial soil and garden soil. Physiological and biochemical parameters were measured in the study. In *C. erectus*, there was a non-significant difference ($P > 0.05$) relative to control, followed by growth across all treatments except for T1 (5% industrial soil), which showed a significant increasing trend every month with a range of 9 to 25 inches, but T2 (10% industrial soil), T3 (15% industrial soil), and T4 (20% industrial soil) showed a non-significant increasing growth pattern ($P > 0.05$). Figure 3A (a-e). In *D. viscosa*, a significant increasing growth trend was observed in the 4th months in T1 (5% industrial soil). There is increase in plant height in case of *C. erectus*, 187% (T1), 257% (T2) and 439% (T3). However, in case of D. viscosa, plant height decreased by 21% (T1) and 79% (T2). For higher levels of industrial soil, plant could not survive (T3 and T4). It can be concluded that a ratio of 10:90 of waste soil to garden soil can be used to establish the plantations of *D. viscosa.* It was also found that 20:80 can be used to establish the plantations of *C. erectus* in such solid waste from the chemical industries. Such findings can be used for the restoration of such solid waste in plantations for the sustainable management of industrial areas and their associated ecosystems.

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Authors' contributions

Conceptualization, writing the original draft: Umair Azam, Muhammad Atif Irshad, .Formal analysis, investigations, funding acquisition. Noor Mirza, Rab Nawaz, Zafar Siddiq, Muhammad Umar Hayyat: resources, project administration, reviewing and editing. Ali Irfan, Abdulaziz Abdullah Alsahli: data validation, and data curation, Mohammed Bourhia, Amare Bitew Mekonnen, Zulkifl Ahmed. Supervision: Muhammad Atif Irshad.

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Availability of data and materials

All data generated or analysed during this study are included in this published article.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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