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Biological Response of Invasive Parthenium Weed to Elevated Concentration of Atmospheric Carbon Dioxide and Soil Salinity

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Abstract: Climate change elements including elevated atmospheric carbon dioxide (CO_2) concentration and soil salinity significantly impact weed biology and management. In this study, we evaluated the performance of a highly invasive plant species, parthenium weed (*Parthenium hysterophorus* L.) grown at various soil salinity levels (ranging from 0 to 16 dS m^{-1}) at two CO_2 concentrations (ambient: 400 ppm and elevated: 700 ppm). The CO_2 concentration and soil salinity individually affected various early growth attributes of parthenium weed. The interaction between CO_2 and salinity was significant for chlorophyll index, stem dry weight and phenolics content. Parthenium weed plants grew taller (13%), achieved greater leaf area (28%) and produced more dry weight (24%) when raised under elevated as compared with the ambient CO_2. Soil salinity had a dose-dependent, negative effect on various growth attributes, chlorophyll index, relative water content and phenolics content. Even the modest levels of salinity (4.2 to 4.6 dS m^{-1}) caused 50% reduction in dry weights of leaves, roots and whole plants. Sodium ion (Na^+) concentration peaked at the highest salinity level (16 dS m^{-1}) as compared with the lower salinity levels (0 to 12 dS m^{-1}). Overall, salinity had a negative effect on different growth variables but elevated CO_2 improved growth and phenolics content regardless of the salt stress regime. Hence, parthenium weed could benefit from future atmospheric CO_2 concentration and may invade some salt-affected areas.

Keywords: climate change; elevated CO_2; ragweed parthenium; *Parthenium hysterophorus*; salinity; invasive alien species

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1. Introduction

Global climate has been changing rapidly, and one of the major drivers of climate change is the rising atmospheric CO_2 concentration [1]. Similarly, soil salinity is a major problem for global food production systems in more than 100 countries [2]. The ambient temperature and soil salinity rise have been exacerbated by rising CO_2 concentration and sea levels, respectively [3]. An increase in air temperature and inland soil salinity could have adversely impact crop production [4]. The effects of climate change drivers on various field and horticultural crops are studied in detail [5–8]. However, such impacts on crop pests, especially weeds, are less explored yet extremely important for sustainable crop production [9,10]. Despite limited data available on this aspect, studies have reported that climate change often influences weeds and invasive plant species positively, resulting in greater interference and production losses [3,9,11–13].

Parthenium weed (*Parthenium hysterophorus* L.) belongs to the family Asteraceae and is one of the most invasive plant species with an ever-expanding introduced range around the world [14]. It is an aggressive, herbaceous weed with multiple morphological and physiological characteristics making it highly adaptable to various biotic and abiotic stresses [14–16]. Massive infestations are often observed on vacant land, disturbed sites, roadsides, railway track sides, and wastelands [15]. Parthenium weed invades and causes significant production losses in many major field crops, including wheat (*Triticum aestivum* L.), rice (*Oryza sativa* L.), sorghum [*Sorghum bicolor* (L.) Moench], maize (*Zea mays* L.), and sugarcane (*Sachharum officinarum* L.) in over 40 countries in Asia-Pacific and Africa [14,15,17]. The weed is also a major production constraint in grazing lands, pastures and livestock systems in many parts of the world [15,18]. In addition, vegetative parts and/or pollen from the weed can cause severe health issues such as contact dermatitis, hay fever (allergic rhinitis), and aggravated asthma (allergic bronchitis) in animals and people [15].

Parthenium weed has been observed to benefit immensely from different climate change drivers. Parthenium weed often tolerates drought, extreme temperatures, and other abiotic stress conditions while outcompeting other plant species [14]. One major climate change driver, elevated CO_2 concentration has been noted to benefit this invasive plant the most [19–22]. Parthenium weed, like many other C_3 plant species, improves its photosynthetic efficiency under elevated CO_2 [23,24], which is the major photosynthetic pathway throughout its life cycle except during the early rosette growth stage, when parthenium weed leaves photosynthesize through a C_3/C_4 intermediate pathway, making it an exceptionally resilient species [14,25]. It has been observed that under elevated CO_2, some C_3 weeds significantly increased their biomass production, resulting in enhanced crop competition and reduced crop yields [26]. Parthenium weed plants have also shown a similar increase in growth, biomass production, and reproductive potential under elevated CO_2 [20,21]. Similarly, parthenium weed has been reported to tolerate salt stress/salinity at different growth stages [27,28]. Recent experimental results indicated that two Australian biotypes of parthenium weed were able to germinate under fairly high levels of salinity imposed as sodium chloride (NaCl) solutions [29]. Hence, this weed has the potential to benefit from a rapidly changing climate and its consequential phenomena, such as soil salinity.

Despite knowing the impact of some individual climate change elements (drought, heat stress, elevated CO_2, salinity) on parthenium weed biology, little is known about the interactive effect of these climate change drivers on parthenium species. Such knowledge is extremely important to predict the weed crop competition in the future and to design suitable interception/management tactics [14]. Literature shows that cultivated plant species/crops tolerate soil salinity better at an elevated CO_2 compared to ambient CO_2 concentrations [30,31]. If this trend holds in case of parthenium weed, it could facilitate parthenium weed's range expansion into salt-affected land as well as into coastal areas. However, we do not know how exactly parthenium weed responds to soil salinity under varying CO_2 concentrations. Therefore, we carried out a controlled environment study hypothesizing that parthenium weed could tolerate soil salinity better under elevated CO_2 which would have the potential to facilitate its future spread. Our objectives were to understand the impact of a likely climate change scenario, i.e., elevated CO_2 concentration $\times$ soil salinity on the early growth of parthenium weed since it is the most important growth stage during invasion, early population establishment, and interference. To explore the full interactive dynamic of these environmental factors, we used five different levels of soil salinity (0 to 16 dS m^{-1}) at ambient (400 ppm) and elevated (700 ppm) atmospheric CO_2 concentrations. The results of this study provide crucial information about future invasion potential/risk and possible management interventions for parthenium weed.

2. Materials and Methods

2.1. Experimental Design and Setup

The study was carried out under controlled environmental conditions at the Gatton Campus of the University of Queensland, Australia during 2018 and repeated once during the same year. A completely randomized design with a factorial arrangement of two treatment factors viz., CO_2 concentration (ambient = 400 ppm and elevated = 700 ppm) and soil salinity levels (0, 4, 8, 12, and 16 dS m^{-1}) with four replications (single pot per replicate) per treatment was followed.

This study used two identical growth chambers with complete control of light, humidity and CO_2 (Percival model E-75L1, Percival Intellus Control Systems Ltd., Brisbane, Australia). The parthenium was grown in a growth chamber illuminated with white lighting (photosynthetic photon-flux density of ca. 800 to 1000 µmol m^{-2} s^{-1}) at soil level with a relative humidity of 60 ± 5%. The day/night temperatures were set at 28/18 °C for a 12/12 h matching photoperiod [21]. One of the growth chambers was supplied with CO_2 (food grade from a G-size cylinder) to attain the elevated CO_2 concentration of 700 ppm and was regularly monitored using a hand-held monitor (CO_2METER.com, Ormond Beach, FL, USA). The other chamber operated at an ambient, laboratory atmospheric CO_2 concentration of 400 ppm with no external supply. The chambers were swapped for CO_2 enrichment for the second run. There was a fluctuation of ±10 to 15 ppm in CO_2 concentration in both the growth chambers during the experimental period.

Parthenium weed seeds were collected near Helidon Spa, Queensland, Australia, from a naturally growing population. The seeds were air-dried under shade for 3 to 4 days, cleaned, and stored in a seed store (maintained at 15 °C and 15% relative humidity) until used for this study (ca. 9 months later). Before this study, the fill rate of a selected, representative lot of seeds was determined by an X-ray machine (Faxitron MX-20 Radiography system, Faxitron Biotics, Wheeling, IL, USA), and the seed lot was found to be 98% filled.

Heavy clay loam soil was collected from the Research Farm of the University of Queensland, Gatton Campus, Australia for this study. The soil was air-dried and ground to pass through a 5 mm sieve. The salinity levels of 4, 8, 12, and 16 dS m^{-1} were imposed by adding three salt saline solutions prepared by dissolving the required amounts of salts, sodium chloride (NaCl), calcium chloride ($CaCl_2$), and magnesium sulphate ($MgSO_4$) (Sigma Aldrich, St. Louis, MO, USA) in equal proportions in ultrapure Milli-Q water. The saline solution of desired concentration was directly applied to the sieved soil, then thoroughly mixed and covered with a plastic sheet to minimize the evaporation loss and kept for three days to reach equilibrium [32]. Ten filled seeds of parthenium weed were directly sown into plastic pots (8 cm diameter, 20 cm depth) filled with soil having different salt levels. Desalinated water was sprinkled onto these pots as needed to achieve an optimal soil moisture level (i.e., 80 to 90% of soil water holding capacity), as determined in a previous study [33]. This practice was continued throughout the study. After seedling emergence, three healthy seedlings per pot were maintained initially (the first week after emergence was completed), and a single, vigorously growing seedling was maintained in the following weeks for further growth.

2.2. Experimental Observations and Analyses

Germination percentage was calculated based on the emergence count in all treatments once all ten seedlings had emerged in the non-saline control treatment placed at an ambient CO_2 concentration [21]. Plant growth attributes were recorded from single plants maintained in all treatments at the termination of the experiment (40 days after seedling emergence). This was chosen as an appropriate time during the parthenium weed's vegetative growth stage to represent the plant's early growth [21,33]. Plant height was measured from the base of the plant to the tip of the tallest leaf/shoot. The number of fully expanded leaves per plant was recorded at the same time. The leaf area was measured from fully expanded leaves using a portable leaf area meter (Li-3000C, Li-Cor, Lincoln, NE, USA). The chlorophyll index was estimated from readings taken with a self-calibrating Soil Plant Analysis Development (SPAD) chlorophyll meter (SPAD 502, Konica Minolta, Tokyo, Japan) and expressed as SPAD units. The SPAD data were recorded from three tagged and fully expanded leaves of each plant. The average of five measurements per plant was taken to represent the chlorophyll index. Plants were gently pulled from the soil from the experimental pots, and the roots were washed in running water to remove the adhering soil.

Stem, leaves, and roots were separated, and the length of the stem and root were recorded. Then, stem, leaves, and root samples were separated and dried at 90 °C for 72 h to record their respective dry weights. Relative water content (RWC) percentage was measured from the fresh leaves using the below Equation (1) following the methodology suggested [34]:

$$\text{RWC}(\%) = \frac{(\text{Fresh weight} - \text{Dry weight})}{(\text{Turgid weight} - \text{Dry weight})} \times 100 \tag{1}$$

For total soluble phenolics determination, a fresh leaf sample was taken from a penultimate leaf (ca. 3 g) from a single plant in each replication at 35 d after seedling emergence. Samples were stored at 4 °C in zip-locked plastic bags until used for chemical analysis. A 0.5 g sub-sample of fresh leaf material was macerated in 10 mL of 80% acetone (*v/v*) and centrifuged at 5000 rpm for 15 min. After centrifugation, 1 mL of supernatant was mixed with 0.5 mL of Folin-Ciocalteau reagent (Sigma Aldrich, MO, USA), and the absorbance of the solution was recorded at 750 nm using a spectrophotometer. The soluble phenolics content was expressed as a gallic acid equivalent [33,35].

To determine the Na^+ and K^+ content, plant samples (0.5 g) were weighed, dried, finely ground, then subjected to wet digestion with nitric acid and perchloric acid using the method of Zasoski and Burau [36]. Perkin Elmer Optima Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES) was used to determine Na^+ and K^+ content.

2.3. Statistical Analysis

Data were analyzed using the software Statistix (ver. 8.1, Tallahassee, FL, USA) and SigmaPlot (ver. 14.5, Systat Software Inc., San Jose, CA, USA). Data from two runs were subjected to analysis of variance (ANOVA), which revealed that the effect of the run was non-significant. Therefore, data from both runs were pooled for further analyses. An ANOVA was then performed on all variables/parameters for a completely randomized design in a factorial arrangement to determine the significance of treatment factors, i.e., CO_2 concentration and soil salinity levels, and their interaction. After ANOVA, mean values for the parameters significantly affected by CO_2 treatment were separated using the least significance difference (LSD) test at 5% probability level ($p < 0.05$). Given the fact that the soil salinity treatment was quantitative in nature, regression analysis was performed. After testing different non-linear regression models, a three-parameter, sigmoidal, sigmoid regression model (2) was found to be the best fit for all variables except for total soluble phenolics content, so that data was analyzed using a three-parameter, sigmoidal, logistic regression model (3) Single dose response curves were prepared for the variables that showed no significant interaction between CO_2 concentration and soil salinity. In contrast, separate curves were prepared for the two CO_2 concentrations where the interaction of variables was significant. The coefficients of determination (R^2) values were used to determine the goodness of fit of the selected model.

$$y = \frac{a}{1 + e^{-\left(\frac{x - xo}{b}\right)}} \tag{2}$$

$$y = \frac{a}{1 + e\left(\frac{x}{xo}\right)^{b}} \tag{3}$$

The soil salinity level causing 50% reduction in any variable (SL_{50}) was calculated based on the regression equations. Standard errors of treatment means were also presented as an estimate of variability in all graphs.

3. Results and Discussion

3.1. Effect of the Increased CO_2 Level

Elevated CO_2 concentration (700 ppm) increased the plant height, leaf area, leaf dry weight, and total dry weight of parthenium weed as compared with the ambient CO_2 concentration (400 ppm), independent of soil salinity level (Figure 1a–d).

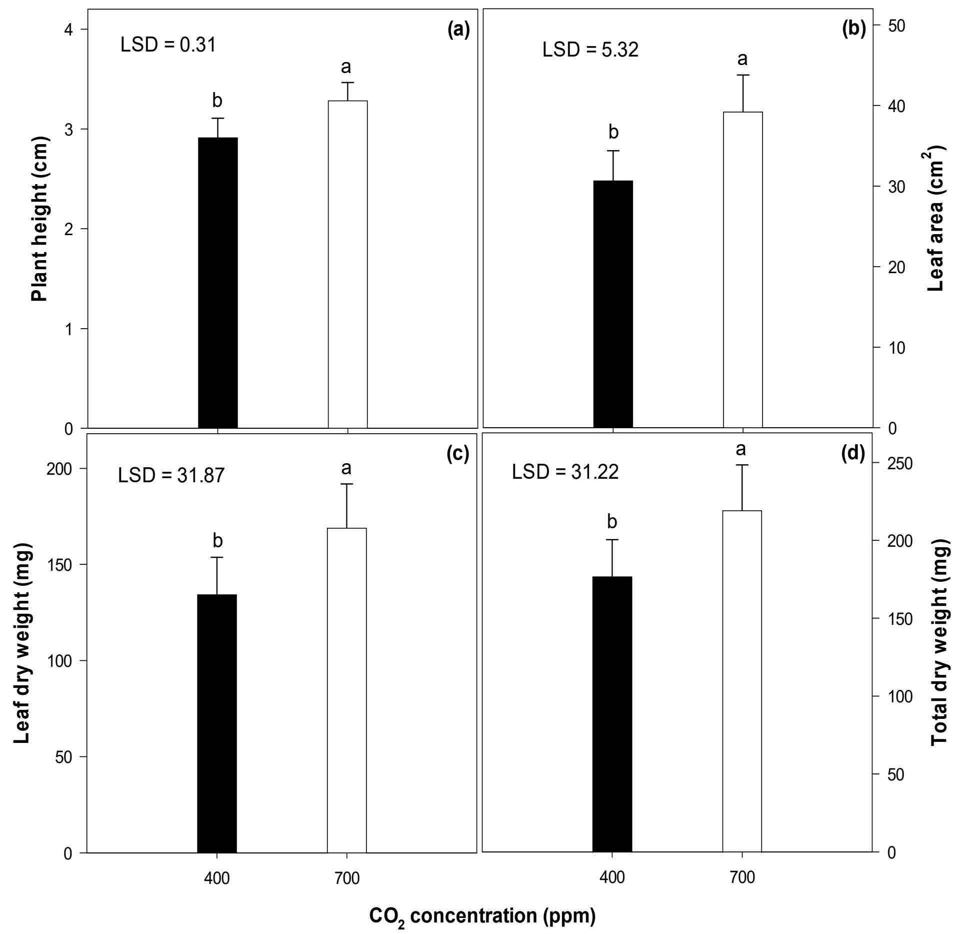

Figure 1. The effect of ambient (400 ppm) and elevated CO_2 concentration (700 ppm) on (**a**) plant height, (**b**) leaf area per plant, (**c**) leaf dry weight per plant and (**d**) total dry weight per plant of parthenium weed plants 40 days after emergence. The bars sharing different letters in each plot significantly differ according to the least significant difference (LSD) test at $p < 0.05$. Error bars represent ± standard errors of the treatment mean.

The plants grown under elevated CO_2 concentration had an increased plant height (13%), leaf area per plant (28%), leaf dry weight (26%), and total dry matter production (24%) compared to ambient CO_2 concentration (Figure 1a–d). Elevated CO_2 concentration influence the physiological processes, lead to improved photosynthetic efficiency [37] and increased starch accumulation. For example, common lambsquarters (*Chenopodium album* L.) plants were found to increase the leaf dry weight despite under reduced rubisco concentration during long-term CO_2 exposure [38] Previously, under a relatively modest increment in CO_2, a significant increase in the growth of a young parthenium plant was observed under different temperatures [39]. In the present study, the increases in the total dry matter production of young parthenium plants at elevated CO_2 concentration can be associated with increased plant height, leaf dry weight, and leaf area. The increased total dry matter production in parthenium under short term elevated CO_2 exposure might be due to the improved photosynthetic efficiency [23,24]. However, unlike in previous studies, the number of leaves per plant did not vary significantly across CO_2 concentrations (data not presented). At elevated CO_2 concentration, increased leaf area could have led to a higher photosynthetic rate, as evident by a higher chlorophyll index, which might have translated into increased biomass production. In C_3 plants like parthenium, elevated CO_2 concentration might have increased the rubisco carboxylation activity and thus reduced the oxygenase activity. Thus, there could be a reduction in CO_2 loss through the photorespiration process [40,41]. Hence, the elevated CO_2 concentration might have increased the photosynthetic rate, which could have increased the growth of parthenium plants, as evidenced by an increased plant dry weight.

3.2. Effect of Soil Salinity Level

Soil salinity levels affected all measured morphological and physiological attributes of parthenium weed and mostly were independent of CO_2 concentration, except for stem dry weight per plant (mg), chlorophyll index, and total phenolics content (Table 1).

Table 1. Analysis of variance for different morphological and physiological attributes of parthenium weed at different CO_2 concentrations and soil salinity levels. The p values < 0.05 are significant.

Source of Variation	***p* Values for Different Treatment Factors**		
	CO_2	**Salinity Level**	**Interaction**
Germination (%)	0.255	<0.001	0.969
Plant height (cm)	0.022	<0.001	0.347
Numbers of leaves per plant	0.250	<0.001	0.543
Chlorophyll index (SPAD units)	<0.001	<0.001	0.029
Leaf area per plant (cm^2)	0.003	<0.001	0.233
Leaf dry weight per plant (mg)	0.034	<0.001	0.654
Stem dry weight per plant (mg)	0.020	<0.001	0.003
Root dry weight per plant (mg)	0.306	<0.001	0.219
Total dry weight per plant (mg)	0.009	<0.001	0.195
Root length per plant (cm)	0.769	<0.001	0.704
Relative water content (%)	0.519	0.002	0.538
Total soluble phenolics (mg g^{-1} of fresh weight)	0.056	<0.001	<0.001
Sodium (%)	0.817	0.012	0.999
Potassium (%)	0.169	0.346	0.959

The measure of all attributes declined in a dose-dependent manner except for the sodium (Na^+) concentration that increased with increasing soil salinity levels (Figures 2–5). The seed germination percentage ranged between 56 and 96% across the soil salinity levels applied, with a 50% reduction in germination predicted at 16 dS m^{-1} (Figure 2). Plant height, the number of leaves per plant, and leaf area per plant were reduced by 177%, 157%, and 2188% at the highest level of soil salinity (16 dS m^{-1}) as compared to the non-saline control treatment (0 dS m^{-1}) (Figure 3a–c).

The 50% reduction in plant height, number of leaves per plant, and leaf area, as compared to the non-saline control treatment, was predicted to occur at 11.9, 14.5, and 5.9 dS m^{-1}, respectively.

The dry weight of leaves, roots, and total plant biomass also reduced sharply with increasing soil salinity (Figure 4a,c,d). The salinity level required to reduce these three weights by 50%, as compared to the non-saline control treatment ranged from 4.2 to 4.6 dS m^{-1}, respectively (Figure 4a,c,d). Similarly, root length and the relative water content in leaves were negatively affected by increasing the soil salinity (Figure 5a,b). The root length was predicted to reduce by 50% over the non-saline control treatment at a salt level of 12.2 dS m^{-1} (Figure 5a). The highest soil salinity level (16 dS m^{-1}) caused a 26% reduction in relative water content (Figure 5b). The concentration of Na^+ in leaf tissues increased with increasing level of soil salinity, and a 50% increase was predicted to occur at a soil salinity level of 12.5 dS m^{-1} (Figure 5d).

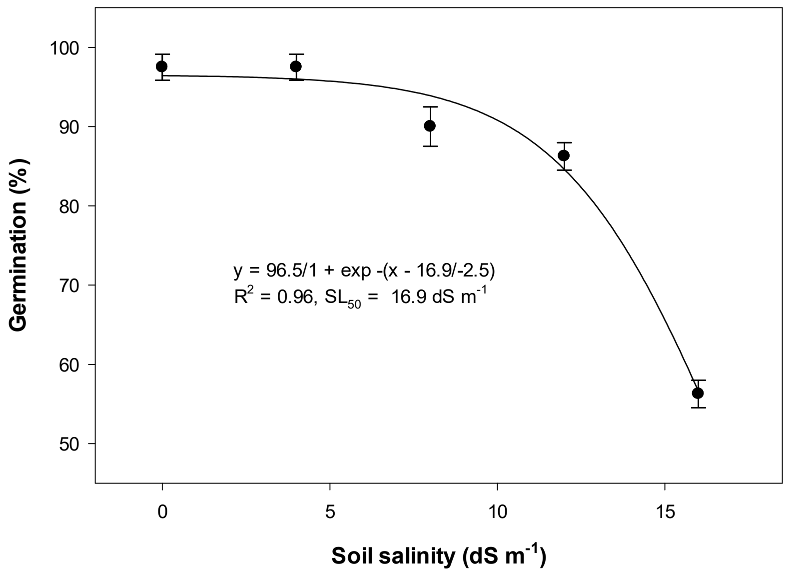

Figure 2. The effect of different levels of soil salinity (0 to 16 dS m^{-1}) on seed germination percentage of parthenium weed plants 40 days after emergence. Error bars represent ± standard errors of the treatment mean. Data are pooled for two CO_2 concentrations as there was no significant interaction between CO_2 concentration and soil salinity level for this variable.

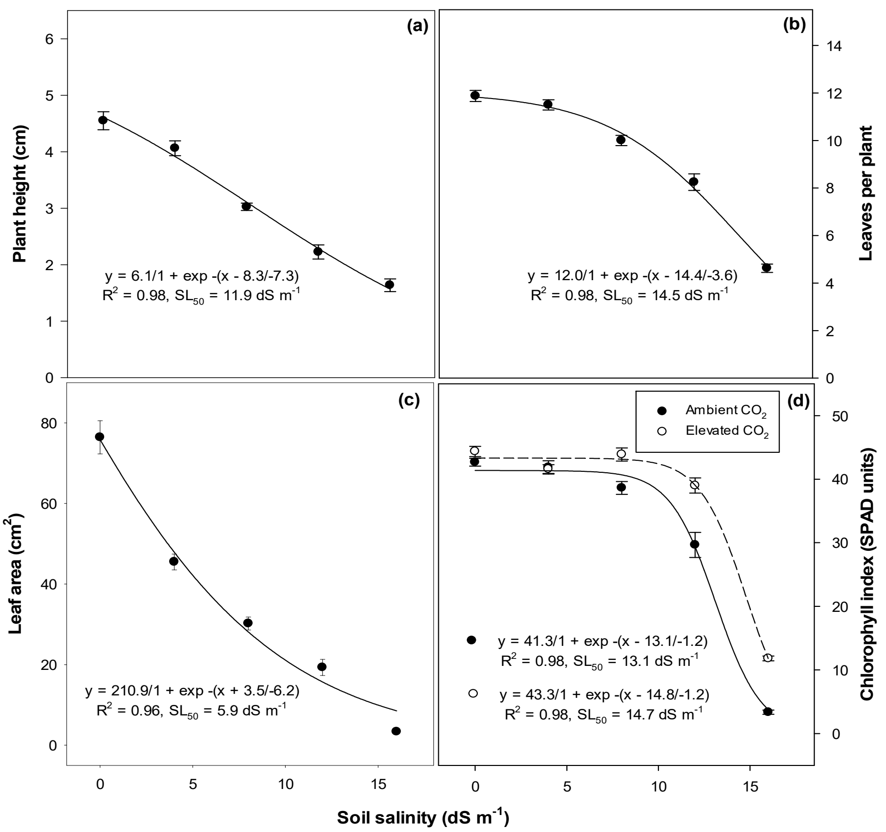

Figure 3. The effect of different levels of soil salinity (0 to 16 dS m^{-1}) on (**a**) plant height, (**b**) number of leaves per plant, (**c**) leaf area per plant and (**d**) chlorophyll index of parthenium weed plants 40 days after emergence. Error bars represent ± standard errors of the treatment mean. Data are pooled for two CO_2 concentrations for all attributes except chlorophyll index as the interaction between CO_2 concentration and soil salinity level was only significant for this variable.

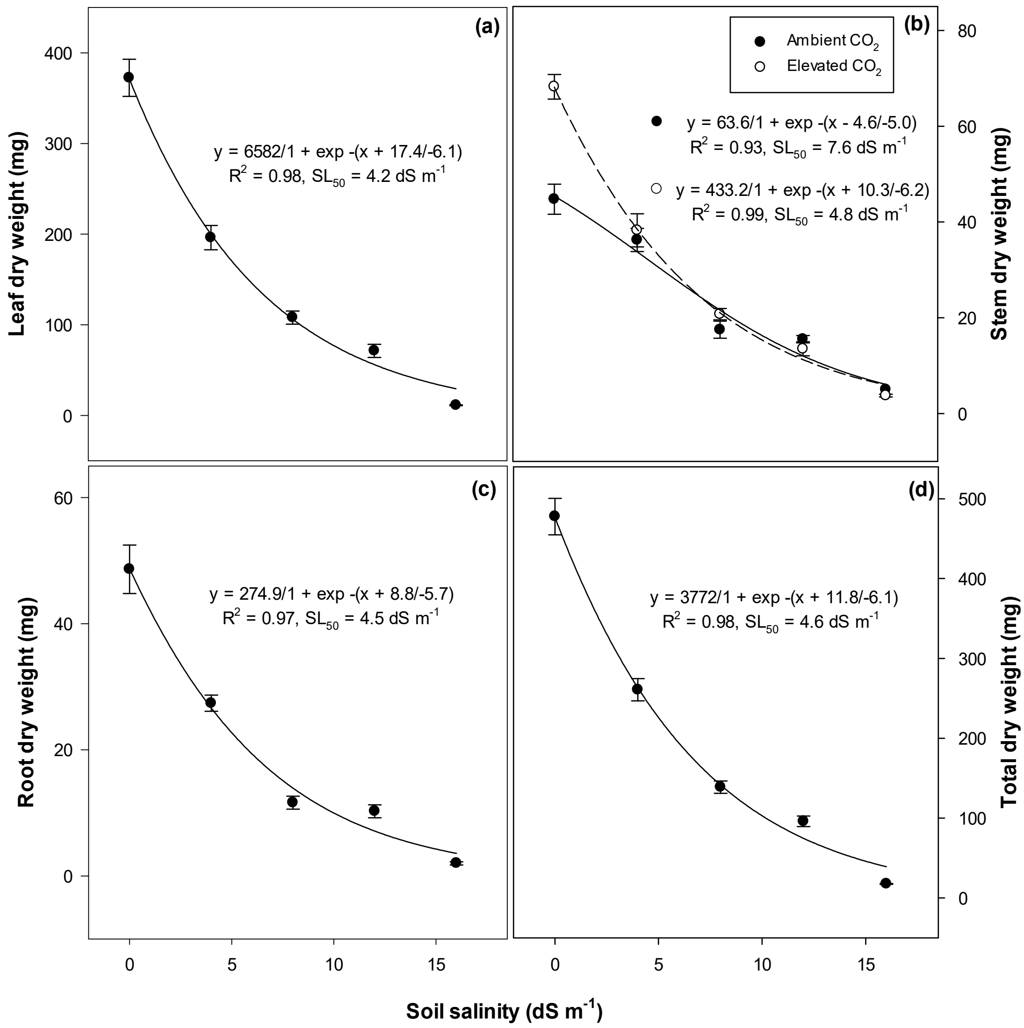

Figure 4. The effect of different levels of soil salinity (0 to 16 dS m^{-1}) on (**a**) leaf, (**b**) stem, (**c**) root, and (**d**) total dry weights (per plant) of parthenium weed plants 40 days after emergence. Error bars represent ± standard errors of the treatment mean. Data are pooled for two CO_2 concentrations for all attributes except stem dry weight as the interaction between CO_2 concentration and soil salinity level was only significant for this variable.

Salt stress drastically inhibits seed germination in many species [42]. The ability of a seed to germinate successfully under saline conditions has been associated with greater competitiveness in different weeds and invasive plant species, including parthenium weed [29]. Highly invasive biotype of parthenium weed had superior germination ability under salt stress compared to its non-invasive counterpart [29]. In the present study, parthenium seed germination ability was sustained at moderate salinity up to 12 dS m^{-1} before reducing drastically at high salinity (16 dS m^{-1}). The inhibition of germination under high salt stress can be attributed to various physiological disruptions in metabolism caused by ion toxicity or high osmotic stress [43]. Previously, a substantial reduction in seed germination and early growth of parthenium weed has been reported under saline conditions. This is mainly because the salinity treatment was imposed directly on the growing plants, which could be more damaging as compared to saline soil conditions [27]. It has been noted that sodium ion (Na^+) accumulation leads to chlorophyll breakdown and reduction in photosynthetic pigments such as chlorophyll *a* and *b* under salt stress [44,45]. These alterations in leaf chlorophyll could be due to impaired chlorophyll biosynthesis or enhanced chlorophyll degradation.

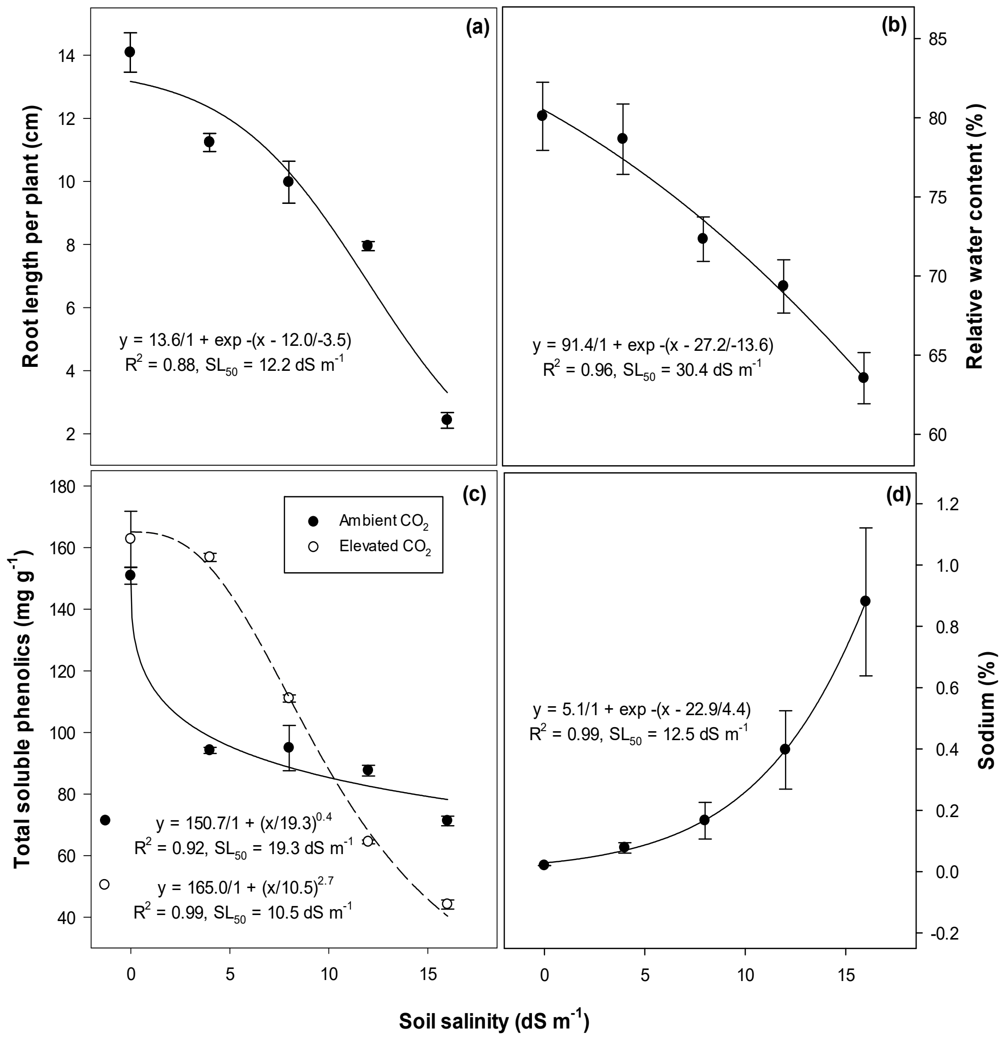

Figure 5. The effect of different levels of soil salinity (0 to 16 dS m^{-1}) on (**a**) root length per plant, (**b**) relative water content in leaves, (**c**) total soluble phenolics content in leaf tissues and (**d**) sodium (Na^+) concentration in leaf tissues of parthenium weed plants 40 days after emergence. Error bars represent $\pm$ standard errors of the treatment mean. Data are pooled for two CO_2 concentrations for all attributes except total soluble phenolics as the interaction between CO_2 concentration and soil salinity level was only significant for this variable.

3.3. Interactive Effect of CO_2 and Soil Salinity

The interaction between CO_2 concentration and salinity level was only significant for leaf chlorophyll index, stem dry weight, and total soluble phenolics content (Table 1). Chlorophyll index was the highest for plants grown in the non-saline soil (0 dS m^{-1}) at elevated CO_2 concentration, while the lowest chlorophyll index was recorded for plants grown at the highest salinity level (16 dS m^{-1}) at ambient CO_2 concentration (Figure 3d). Overall, the salinity level predicted to cause 50% reduction in chlorophyll index was highest at elevated CO_2 concentration (14.7 dS m^{-1}) as compared to ambient CO_2 concentration (13.1 dS m^{-1}) (Figure 3d). Plants grown in the non-saline soil (0 dS m^{-1}) produced the highest stem dry weight while those grown in the highly saline soil (16 dS m^{-1}) produced the lowest stem dry weight at elevated CO_2 concentration (Figure 4b). Under elevated CO_2 concentration, the highest soluble phenolics content was observed at 0 and 4 dS m^{-1}. However, at ambient CO_2 concentration, the highest was observed at 0 dS m^{-1}. The soluble phenolics contents were decreased with increasing soil salinity levels (Figure 5c). Overall, plants grown at ambient CO_2 concentration were predicted to require almost twice the amount of salt (19.3 dS m^{-1}) for 50% reduction in total soluble phenolics content as compared to those grown under an elevated CO_2 concentration (10.5 dS m^{-1}) (Figure 5c).

This study reveals that CO_2 concentration and soil salinity did not interact to any great degree to influence parthenium weed growth, except for stem dry weight. Nevertheless, significant interactions were observed for chlorophyll index and total soluble phenolics content suggesting these physiological variables were more sensitive to CO_2 concentration change under saline conditions. The results of the present study also indicate that elevated CO_2 improved growth and biomass production of parthenium weed plants regardless of the soil salinity levels applied. Carbon enrichment could still benefit plants under stressful conditions such as salinity. However, CO_2 enrichment did not affect parthenium weed seed germination/emergence from soil. Previous studies have shown that parthenium weed achieved greater competitive advantage under elevated CO_2 concentration as evidenced by taller plants, increased leaf area, and greater biomass production [19–21,46]. Soil salinity had varying degree of negative influence on all variables studied, suggesting that parthenium weed plants are typically sensitive to higher levels of salt stress. However, the magnitude of the negative effects of salinity varied for different growth and physiological attributes.

Elevated CO_2 concentration positively affected chlorophyll content under salt stress, indicating that these plants might survive salt stress if supplied with additional CO_2. Enhanced production of soluble phenolics at an elevated CO_2 concentration might have played an important role in plant growth regulation, especially under saline conditions. Previously, an increase in phenolic concentration and higher levels of non-structural carbohydrates such as starch and sugars were reported at an elevated CO_2 concentration in wheat [47]. It was reported that elevated CO_2 promoted carbon assimilation, which led to a change in the carbon-based secondary compounds viz. the phenolic content in the plant tissues under salinity stress. Similar to the present study, drought stress also induces phenolics accumulation in leaves [48]. In this present study, water-stressed conditions in plants might have occurred due to the reduction in the relative water content as salinity increased. Reduced transpiration rates and oxidative stress, with increased water use efficiency, intracellular Na^+/K^+ and cellular hydration are some of the physiological changes observed under salinity stress [30,49]. Elevated CO_2 concentration resulted in an increase in the above-ground biomass, in particular, stem dry weight under low salinity stress. This indicates the benefit of carbon enrichment in improving the vegetative biomass due to a greater sink capacity [24,50].

4. Conclusions

The present study clearly indicates that an elevated CO_2 concentration promotes parthenium weed growth, not only in normal soil but also in saline soils. Therefore, CO_2 concentration forecasted for the future climate may facilitate parthenium weed invasion into the areas with saline soils where few other competing plants could exist. Growth and development of parthenium weed are two processes negatively affected by high salt stress, but their plants can generally tolerate moderate salinity fairly well as compared to many crops or native plant species. However, the present study is only focused on early plant growth; future studies should look at parthenium weed's response to these conditions at different growth stages and monitor the effect on its flowering behavior and seed set pattern. Furthermore, impact of other climate change elements such as heat and drought stress should be studied in conjunction with salinity and elevated CO_2 concentration to reveal the full extent of the biological response and invasion potential of parthenium weed in future climatic conditions.

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Conflicts of Interest: The authors declare no conflict of interest.

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