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The Growth of *Chenopodium Murale* Irrigated with Polluted and Unpolluted Water: a Modeling Approach

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Abstract: A random sample of 407 individual plants of *Chenopodium murale* growing in two sites one irrigated with polluted water (polluted area) and the other irrigated with unpolluted water (unpolluted area) were collected to determine the effects of water pollutants on the growth parameters of this medicinally important plant using Richard's, Von Bertalanfi and Gompertz growth models. The parameters of the three growth models were calculated for plants growing in the polluted and unpolluted areas using petiole length, leaf width, stem width, root length, petiole dry weight, leaf length and leaf dry weight as the growth determining factors. There were differences in the growth rates, growth period and the age at which the parameter is theoretically nil of plants growing in the unpolluted area from those growing in the polluted area. These differences show that water pollutants reduced the growth rate of the plant leaf, petiole, stem and root and decreased the growth period compared to the plants irrigated with unpolluted water.

Key words: Growth models, *Chenopodium murale*, water pollution, growth parameters, Nonlinear modeling

INTRODUCTION

Allocation in plants and many ecological processes are better understood in terms of growth and size than in terms of time. Plants evolve allometric patterns in response to numerous selection pressures and constrains, and these allometric patterns explain many behaviors observed in plant populations (Weiner, 2004). For example, changes in the pattern of allocation of meristems to growth may result in alteration in the morphology and architecture of plants (Bonser and Aarssen, 2001) and these changes within a species can be related to the emergence of strategies that may maximize fitness in a given environment. Moreover, plant parts that are subjected to diversifying forces will often end up with weak or non-existing phenotypic correlations between organs (Herrera, 2005).

A number of studies used modeling to study the influence of stress and stimulus factors from air and soil on plant growth (Chen *et al.*, 1998), the interacting effects of browsing and shading on mountain forest tree regeneration (Weisberg *et al.*, 2005) or the optimal root-shoot allocation and water transport in clonal plants (Stuefer *et al.*, 1998). Moreover, other studies examined the effects of pollutants on the growth and allometry of plants. Grantz and Yang (2000) studied the ozone impacts on allometry and root hydraulic conductance and reported that ozone induces an allometric shift in carbohydrate allocation. Kruse *et al.* (2003) examined the effects of elevated carbon dioxide partial pressure on growth, allometry, and nitrogen metabolism of poplar plants. Their results indicated that elevated carbon dioxide partial pressure increased total biomass and the root: shoot ratio at deficient nitrogen-supply plants. Muzika *et al.* (2004) reported that ozone (O_3), nitric dioxide (NO_2) and sulfur dioxide (SO_2) adversely influence the growth of *Picea abies* and *Fugus sylvatica* plants. Furthermore, researchers have reported that exposure to SO_2 elicit multiple events linked to defense / stress responses in the leaves of rice seedlings (Rakwal *et al.*, 2003), affects metabolism of *Mangifera indica* plants (Farooq and Hans 1999), and alters yield of soybean grain (Xiong *et al.*, 2003). The effect of air pollution on the growth parameters of the medicinal plant *Urtica urens* (small nettle) were reported by Elkarmi and AbuEideh (2006) who found that air pollutants reduced the height of plants, increased the growth period, increased the length of petioles and the weight of leaves of plants growing in a polluted area.

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Few studies were carried out to evaluate the linkage between water pollutants and the growth patterns of plants. Most of these studies concentrated on modeling growth under different stress conditions. Latore *et al.* (1999) examined the effects of habitat heterogeneity and dispersal strategies on population persistence in annual plants. They calculated which habitat heterogeneity gives populations the best chance of persistence. Karlberg *et al.* (2006) used an integrated ecosystem model to simulate growth and transpiration over a range of salinities. Thornley and France (2005) applied an open-ended logistic based growth model to determine the growth of organisms under limiting growth conditions such as temperature, nutrition, or irradiance.

The Nettleleaf goosefoot is an annual, green, sparingly mealy plant with an ascending to erect branching. The leaves are petiolate, rhombic and are acutely dentate-serrate. Inflorescences axillary and terminal, branched with dense or loose clusters with hermaphrodite flowers. The Seeds are lenticular, minutely pitted, and black. (Zohary, 1972).

The purpose of our study is to determine the growth models of *Chenopodium murale* L. **(**Nettleleaf goosefoot**)**, that has wide applications in folk medicine in Jordan and many other countries, growing in water polluted and unpolluted areas in order to determine the effects of water pollution on the growth of this plant. The growth parameters of this plant will be calculated using Von Bertalanfi, Gompertz and Richard's growth models.

MATERIALS AND METHODS

Study Sites and Species:

Zarqa Basin is located to the north west of Amman between 35º-8' and 36º Nº latitudes and 32º-8'- 33º-4' E longitudes. It is divided into four main parts. Aqib Area, Dhuleil-Hallabat Area, Dhuleil-Sukhnah Area and Amman –Zarqa area. The quality of water widely varies in the four Zarqa Basin parts. The two studied sites were the Amman-Zarqa Area as water polluted site where water quality is highly affected by human activities where more than 50% of the population in Jordan live and most of the industries located there. According to the Royal Scientific Society-Ministry of Water and Irrigation report (1998-1999), the ground water salinity may reach 8000 mg/1. In collaboration with Higher Council for Science and Technology- Environmental Monitoring and research Central Unit in Jordan which carry out daily, weakly and monthly monitoring of water quality, the levels of heavy metals of Fe (maximum of 2.0 mg/L), Mn (maximum of 0.26 mg/L), Na (maximum of 273 mg/L), Cl (maximum of 417 mg/L) and HCO3 (maximum of 451 mg/L) in the water of Zarqa Basin were measured. These levels of these metals were above the tolerance levels suggested by FAO for irrigation water (Environment monitoring and research central unit (EMARCU), 2006). Another study showed that several heavy metals were observed such as Cd, NO_3, SO_4, Cl, K, Na, Fe, Pb,Zn, and Cu (Preul, 1997). Significant increases in other chemicals normally associated with industrial discharges were also identified, for example, Cl showed a 6.5-fold increase, NO_3 with a 2.2-fold increase, and SO_4 with a 5-fold increase (The Royal Scientific Society, 2004). The second studied site was Dhuleil-Sukhneh area as the unpolluted water site where water salinity varies between 300-5000 mg/l and no recorded levels of pollutants (Fardous *et al.*, 2004).

Based on rain distribution that is mainly in winter and spring Jordan is classified as Mediterranean bioclimatic region. The two studied areas share all other environmental factors. Both are of Arid Mediterranean bioclimatic region that is characterized by annual rainfall that ranges from 150-300 mm and a westerly to north westerly prevailing wind direction in most times of the year (Al-Esawi 1996). The two areas are located in the Irano-Turanian vegetative regions which are characterized by poor, eroded calcareous (loess) soil type and the vegetation is a timber less (no trees) with mostly shrubs and bushes (Zohary, 1973). *Chenopodium murale* (Nettleleaf goosefoot) is an easily growing weed species having wide adaptation to different climatic regions and experiences a temperature range of 4-45 °Ċ. This plant prefers light (sandy), medium (loamy) and heavy (clay) and can grow in nutritionally poor soil. It prefers a moderately fertile moist soil, and can tolerate drought but dislikes shade (Huxley, 1992). The leaves, and seeds of Nettleleaf goosefoot plant are used locally and in other countries as an anthelminthic, antispasmodic, stomachic diaphoretic , emmenagogue, for the pain of amenorrhoea, as an abortifacient and for the relief of asthma, catarrh and migraine. (Goher & Elmazar, 1997) the dried ripe fruits are used for dyspepsia (Hamayun *et al.*, 2006) . It is worth mentioning that in many countries the leaves and seeds are edible (Moerman, 1998).

Sampling and Measurements:

A random sample of 407 nettleleaf goosefoot plant individuals were collected from an area of 1 Km^2 during the growing season from February to September from both sites, polluted (207 plants) and unpolluted sites (200 plants). Collected samples were placed in plastic bags, sprinkled with water, and returned to laboratory within few hours where their roots were submerged in water for 16 to 20 hours. From each of the chosen plants the largest leaf was harvested by cutting the petiole at a point where it is completely separated from the main axis. Petioles were excised from leaf blades, the blades and their petioles were dried at 70 ºC to constant weight. Plant height, petiole length, leaf leangth, root length, stem width were measured for each sample in addition to determining the dry weights of the petiole and leaf (Chang *et al.*, 2004).

Statistical Analysis

Based on the fact that height in *Chenopodium murale* and many other plants is normally distributed, measured plants were divided into size groups calculated using histogram plots that show normal distribution. This calculation was carried out using computer based statistical software (STATISTICA software for windows, StatSoft, Inc., Tulsa, OK, USA). These plant height groups were used to compute the number of possible cohort sizes that best fit the normal distribution (Elkarmi and Abu Eideh, 2006) which reflect the growth period of the plant. Plant height was used to represent plant growth and was theoretically calculated using Gompertz (Aiba and Kohyama, 1996 and Elkarmi, 1998): $Ht = H\infty\ [e^{(-A*e(-kt))}]$, Richard's: $H_t = H\infty\ [1-A*e^{-kt}]$ and Von Bertalanffy growth models:

$H_t = H\infty\ [1-e^{-k(t\ -\ t0)}]$ (Ismail and Elkarmi, 1999, 2000) where H_t is the plant height at age t, H∞ is the plant height at age ∞, A is the model growth constant, k is the growth coefficient and t_0 is the age at which the length or the other plant parts is theoretically nil. The constants H¥, k and t_0 were calculated using the quasi-Newton method (Ostle and Mensing, 1975). The same models were also applied to petiole length, stem width, leaf width, root length, petiole dry weight, leaf dry weight and leaf length.

The motivation for using three models instead of one was intended to give further support, reliability and accuracy to the findings of one particular model. Although the three models may seem mathematically close, they differ in the way they determine the growth parameters. Thus, confirmation and validation of the calculations may well be achieved. This method uses the means of the results of each group to calculate the growth parameters. In the quasi-Newton method, the second order (partial) derivatives of the loss functions are asymptotically estimated, and used to determine the movement of the model parameters from iteration to iteration. Therefore, the model can successfully predict the growth of the plant part, and any individual variation in the dimensions of these parts.

RESULTS AN DISCUSSION

Results:

On the bases of plant height, the plants growing in the polluted area have a growth period of five cohorts which can be estimated as five months while those growing in the unpolluted area have a growth period of six cohorts (figure 1). The growth parameters of *Chenopodium murale* were calculated by the growth models which successfully predicted the growth of the studied plant parts either as length or weight (tables 1, 2 and 3). These growth parameters were calculated for the plants growing in the polluted area and the unpolluted area. For example, Richard's growth model predicted the growth in the petiole length for plants growing in the unpolluted area to be as:

$$\mathbf{PL = 27.04 * (1 - (1.332 * e^{(-0.45*T)})),}$$

while the growth in the petiole length for plants growing in the polluted area to be as:

$$\mathbf{PL = 47.94 * (1 - (1.098 * e^{(-0.27*T)})).}$$

The actual measurements and relationships between plant height with petiole length, root length, leaf length, leaf width, and stem width are shown in figures (2-5) for plants growing in the polluted and unpolluted areas.

All three models showed that there is a difference in the growth of plants growing in the polluted area from those growing in the unpolluted area (tables 1, 2 and 3) when the petiole length, leaf width, stem width, root length, petiole dry weight, leaf dry weight and leaf length are compared. The growth coefficient (k) indicates the growth rate of the parameters being considered. As predicted by Richard's model, the results showed that the stem width and leaf dry weight of plants growing in the unpolluted area have growth coefficients (1.1 and 1.1 respectively) much higher than the growth coefficient of the plants growing in the polluted area (0.35 and 0.32 respectively). The same behavior is also predicted by the Von Bertalanfi's and Gompertz models. The three models also predicted that the growth coefficients (k) of the other parameters are more for the plants growing in the unpolluted area than for plants growing in the polluted area, although the difference in (k) is not as large as the stem width and leaf dry weight (tables 1, 2 and 3).

Table 1: Results of the Richard's growth model

	Unpolluted Area	Polluted Area
Petiole Length		
PL∞	27.04	47.94
A	1.332	1.098
k	0.45	0.27
r	0.944	0.9725
Leaf Width		
LW∞	22.229	63.549
A	0.796	1.066
k	0.65	0.33
r	0.727	0.9774
Stem Width		
SW∞	5.232	10.441
A	0.7566	0.4997
k	1.1	0.35
r	0.835	0.968
Root Length		
RL∞	186.213	295.088
A	1.171	1.258
k	0.71	0.28
r	0.682	0.8402
Petiole Dry Weight		
PDW∞	8.241	76.261
A	1.909	1.383
k	0.61	0.21
r	0.8795	0.716
Leaf Dry Weight		
LDW∞	90.989	208.798
A	3.094	1.411
k	1.1	0.32
r	0.685	0.919
Leaf Length		
LL∞	69.143	117.021
A	1.203	0.945
k	0.35	0.21
r	0.905	0.958

PL∞, LW∞, SW∞, RL∞, PDW∞, LDW∞, LL∞: parameter at age ∞ (maximum length or weight)
k: growth coefficient
r: correlation coefficient
A: growth model constant

Table 2: Results of the Von Bertalanfi's growth model

	Unpolluted Area	Polluted Area
Petiole Length		
PL∞	23.850	49.945
to	0.746	0.3169
k	0.68	0.25
r	0.9002	0.975
Leaf Width		
LW∞	20.988	58.779
to	0.086	0.2915
k	1.1	0.4
r	0.6384	0.971
Stem Width		
SW∞	5.1176	10.902
to	0.7566	0.4997
k	1.3	0.32
r	0.809	0.972
Root Length		
RL∞	201.314	355.820
to	0.7302	0.7931
k	0.55	0.21
r	0.7211	0.8585
Petiole Dry Weight		
PDW∞	7.826	86.759
to	1.0526	1.563
k	0.71	0.18
r	0.8557	0.7255

Table 2: Continue

Leaf Dry Weight		
LDW∞	90.989	197.909
to	1.027	1.078
k	1.1	0.35
r	0.685	0.913
Leaf Length		
LL∞	69.143	73.224
to	0.529	0.579
k	0.35	0.85
r	0.905	0.9663

PL∞, LW∞, SW∞, RL∞, PDW∞, LDW∞, LL∞: parameter at age ∞ (maximum length or weight)
k: growth coefficient
r: correlation coefficient
to: the age at which the petiole length, leaf width, stem width, root length, petiole dry weight, leaf dry weight and leaf length is theoretically nil.

Table 3: Results of the Gompertz growth model

	Unpolluted Area	Polluted Area
Petiole Length		
PL∞	25.332	42.158
A	4.709	2.924
k	0.85	0.55
r	0.9355	0.9779
Leaf Width		
LW∞	22.653	72.788
A	1.134	2.159
k	0.68	0.38
r	0.748	0.9889
Stem Width		
SW∞	5.348	11.995
A	6.784	2.929
k	1.4	0.45
r	0.8522	0.9954
Root Length		
RL∞	220.647	376.618
A	5.881	6.896
k	0.78	0.55
r	0.755	0.9123
Petiole Dry Weight		
PDW∞	11.188	71.423
A	6.519	2.75
k	0.62	0.27
r	0.981	0.666
Leaf Dry Weight		
LDW∞	132.175	301.582
A	34.023	5.993
k	1.1	0.48
r	0.873	0.9832
Leaf Length		
LL∞	62.987	92.879
A	4.065	1.887
k	0.71	0.47
r	0.8964	0.9628

PL∞, LW∞, SW∞, RL∞, PDW∞, LDW∞, LL∞: parameter at age ¥ (maximum length or weight)
k: growth coefficient
r: correlation coefficient
A: growth model constant

The maximum length or weight of the parameter as predicted by the models is calculated based on the actual data collected from the field and these measurements also determine the values of the growth constant (A). Although these values are needed to complete the model parameters, they do not influence the growth rates of the plants. The age at which the parameter is theoretically nil (to) which indicates when this parameter starts to grow was smaller for most plant parts in plants growing in the unpolluted area compared to plants growing in the polluted area.

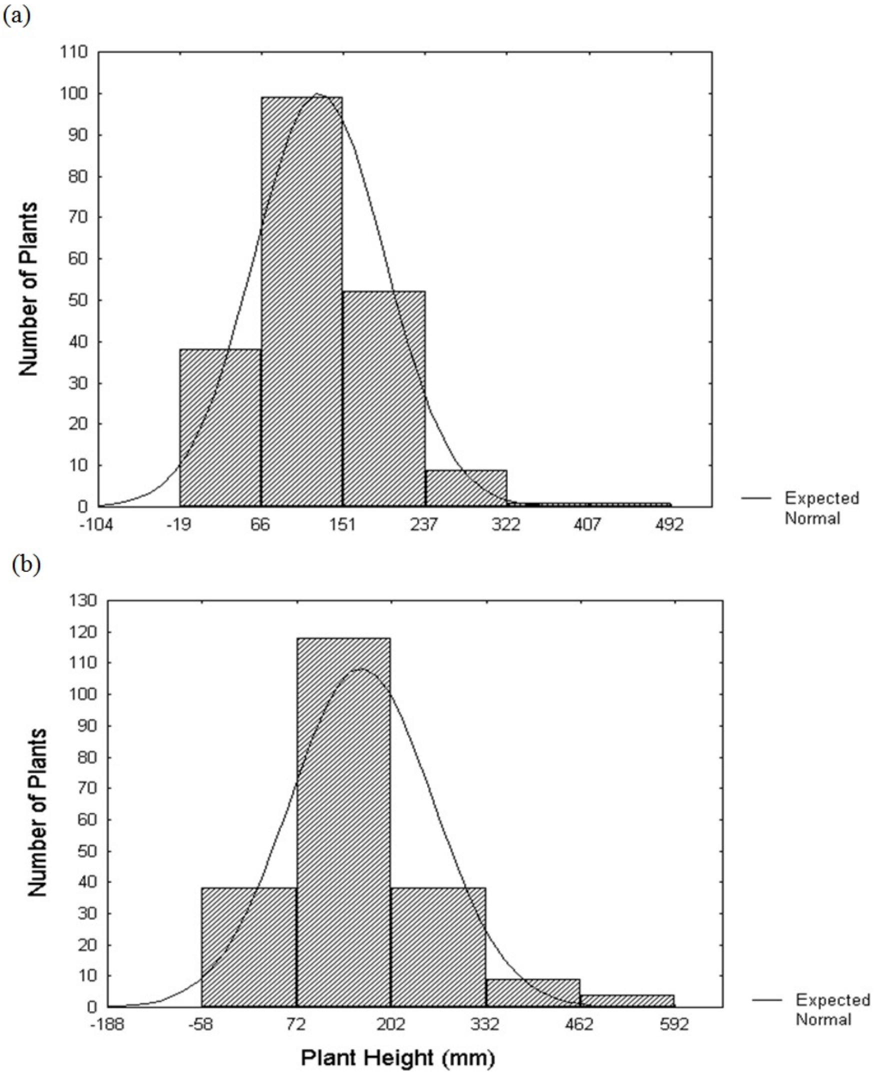
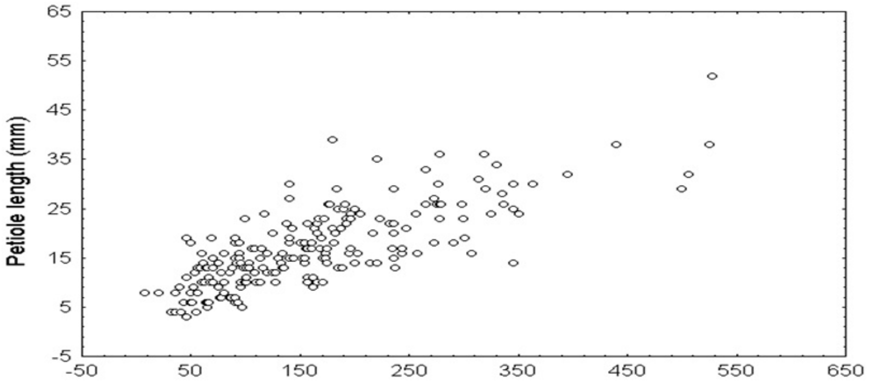


Fig. 1: Frequency distribution according to plant height of estimated length groups showing expected normal distribution for plants growing in (a) unpolluted area and (b) polluted area



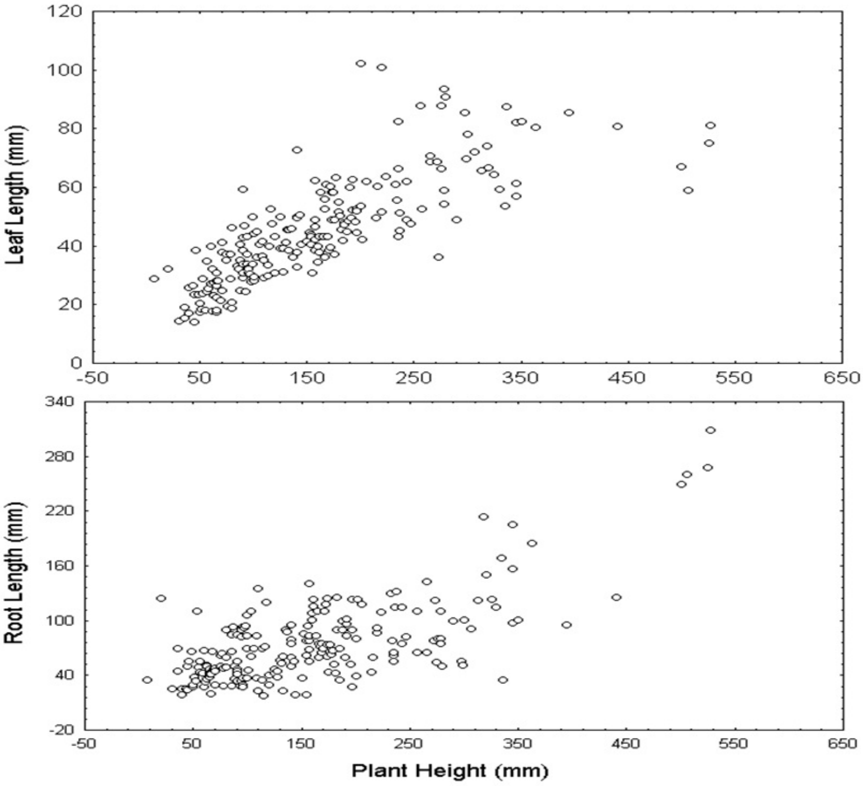


Fig. 2: The actual measurements and relationships between plant height with petiole length, leaf length and root length for *Chenopodium murale* growing in polluted area

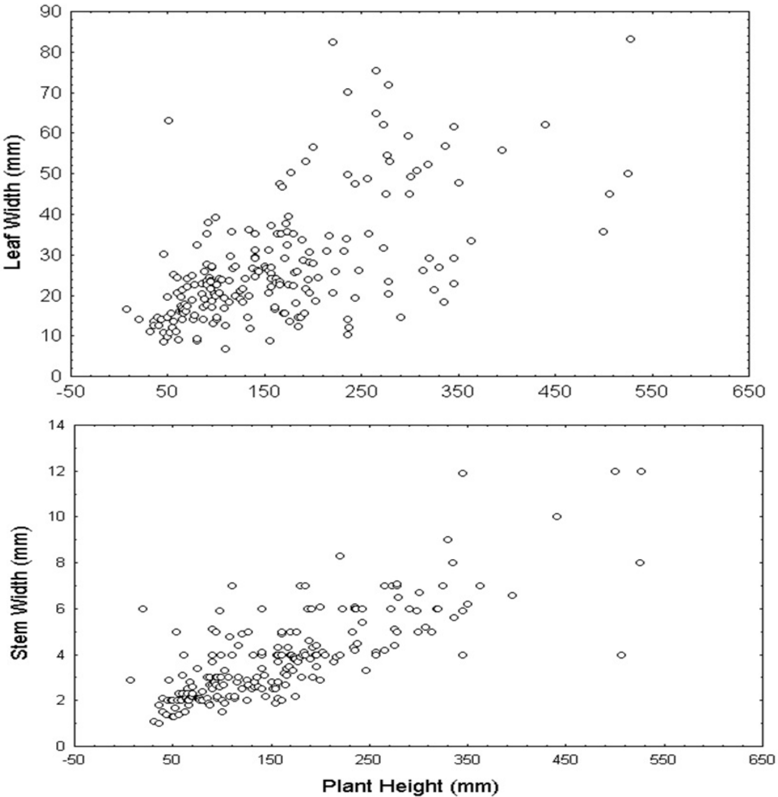


Fig. 3: The actual measurements and relationships between plant height with leaf width and stem width for *Chenopodium murale* growing in polluted area

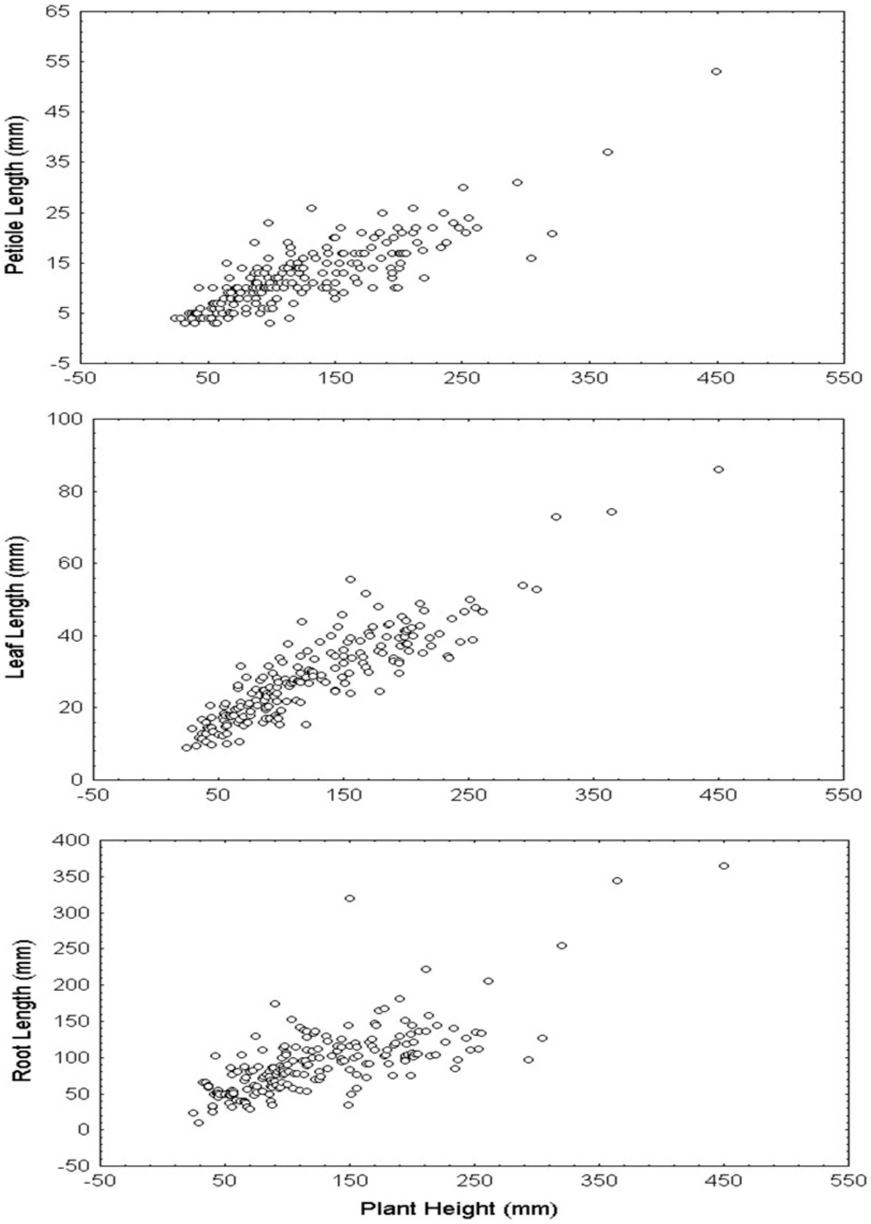
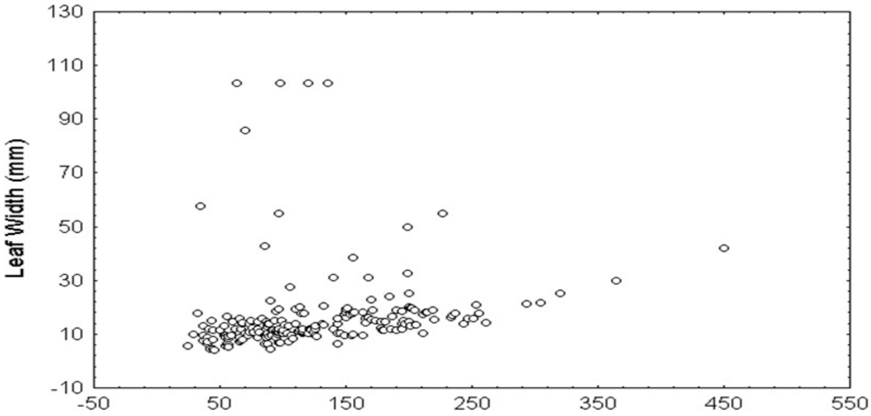


Fig. 4: The actual measurements and relationships between plant height with petiole length, leaf length and root length for *Chenopodium murale* growing in unpolluted area



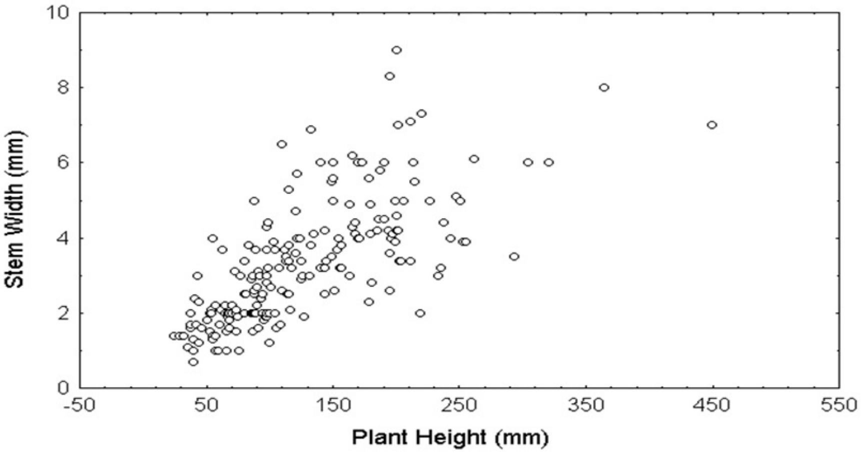


Fig. 5: The actual measurements and relationships between plant height with leaf width and stem width for *Chenopodium murale* growing in unpolluted area

Discussion:

There are differences in the growth rates of the *Chenopodium. murale* growing in the polluted and in the unpolluted areas. The differences which were in the petiole length, leaf width, stem width, root length, petiole dry weight, leaf dry weight and leaf length; indicate that the polluted water source affected mainly the leaf, petiole, stem and root of the plant. This effect is attributed to the presence of certain metals within the water of Zarqa River irrigating the polluted area, and the acidic and saline conditions of water which are primarily a result of increased Na and HCO_3 (EMARCU). Although there have been relatively few studies that examined the growth of *C. murale* and other plant species under different environmental conditions, a number of studies are in agreement with our results. Gardea-Torresdey *et al.* (2005) examined the response of *Salsola kali* under similar concentrations of chromium CrIII and CrVI and found that this plant is able to highly absorb these metals and adjust its root and shoot sizes as a response. Plants that were exposed to 20 mgL^{-1} CrIII and those grown in 20mgL^{-1} CrVI, produced significantly smaller roots as well as shorter shoots compared with the control plants (Gardea-Tooesdey *et al*., 2005). Godbold and Hutterman (1985) studied the effects of zinc and cadmium on root elongation of *Picea abies*. They concluded that increasing zinc levels in culture solution decreased the shoot to root ratios and translocation of Zn, Fe, Mg, K, P, and Ca occurred causing their accumulation within roots. In a similar study on wheat, Pearson and Rengel (1995) reported that the higher concentrations of zinc affect the leaf and root morphology. Arduini *et al.* (1995) studied the influence of copper on root growth and morphology of *Pinus pinea* and *Pinus pinaster* seedlings. They found that the taproot elongation was reduced in the presence of 1μM Copper (Cu) in both species. In another study on the effects of cadmium and copper on the uptake and translocation of five *Salix* species, Kuzovkina *et al.* (2004) found that in twenty-five *μ*M Cadmium (Cd) had an inhibitory effect on *S. lucida*, S. *exigua* and *S. nigra*. Kukkola (1999) examined the effects of copper and nickel on subarctic Scots pine needles. He found that 15 mg Ni kg^{-1} dry soil decreased root growth and increased root tip dieback. 25 Ni mg kg-1 and 50 Cu mg kg-1 dry soil markedly decreased root growth. Halperin *et al.* (2003) reported that the salinity stress inhibits root hair growth and cytosolic Ca^{2+} at the apex of *Arabidobsis thaliana*. Koyama *et al.* (1995) investigated the response of *A. thaliana* to different pH and Aluminum levels and found that the incubation at pH 4.8 or addition of 1 μM $A1C1_3$ at pH 5.0 severely inhibited root elongation. Kidd and Proctor (2001) studied the effects of soil acidic conditions on the growth of *Betula pendula* and *Holcus lanatus*. They reported that under acidic conditions (pH$\leq$4) *H. lanatus* showed decreased root and shoot elongation. *B. pendula* showed decreased root number and decreased leaf area as acidity increased. In a study on the effects of environmental pollution on plant growth, Sharma *et al.* (1980) found that leaf length, leaf width, petiole length, flower size and pod size of *Puerarta lobata* showed a decrease in growth in heavily polluted areas. Khan *et al.* (2000) studied the effects of salinity on the growth of *Atriplex griffithii* and found that dry weight production was significantly inhibited at 360 mM NaCl and increases in salinity caused a progressive decline in root length. Furthermore, different studies were carried out that examined the effects of other pollution factors on the growth parameters of plants. Elkarmi and Abu Eideh (2006) found that air pollutants reduced the plant height, stem width, root length, and petiole length and increased leaf parameters of *Urtica urens*. Prasd and Rao (1981) found that root and shoot lengths, number of leaves, nodules, flowers, and pods were reduced in *Phaseolus aureus* petro-coketreated plants. Our results indicated that there were differences in the growth rates of petiole length and dry weight; leaf length and dry weight; root length and stem width of plants irrigated with polluted water compared to the plants growing in the unpolluted area. A number of reasons for these effects on the growth of the root, stem, petiole and leaf have been reported in the literature. For example, Malea *et al.* (1995) reported that Zn toxicity is primarily associated with root physiology thereby inhibiting the root elongation. Furthermore, the increased salinity (Halperin *et al.*, 2003) and the higher Ni levels (Kukkola, 1999) result in reduced root length and leaf dry weight. As indicated before, the area of Zarqa River (polluted area of our study) is well known for industrial and agricultural activities that usually result in eutrophication. Eutrophication results in high inputs of phosphorus and other agricultural products into the environment (*Horrigan*, 2002). Bates and Lynch (2000) reported that roots become shorter and less dense under higher phosphorus levels. The decrease in leaf length, leaf width, and petiole length in the polluted site agreed with the results of Sharma (1980) that were recorded in a heavily polluted area. Koyama *et al.* (1995) concluded that increased acidity and Aluminum levels cause decreased root lengths, a similar result was obtained by Kidd and Proctor (2001) when recorded that the acidic conditions result in the reduction of leaf area.

In conclusion, heavy metals, acidity and salinity of water in the polluted area resulted in lowering the growth rates of petiole length, leaf width; stem width, root length, petiole dry weight, and leaf dry weight length compared to the growth rates of the plants growing in the unpolluted area. Further studies are needed to determine the causes of these effects.

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