CHAPTER ONE

INTRODUCTION

Garden rocket (*Eruca sativa* Mill.) is an annual plant species belonging to the mustard family Brassicaceae (Cruciferae). Common names include salad rocket, garden rocket, arugula (Bianco, 1995) which is “gargeer” in Arabic. The plant has been known since antiquity and has widely been consumed in various Mediterranean countries for the spicy pungent flavor of the leaves (Padulosi, 1995; Padulosi and Pignone, 1997). The leaves of the plant are eaten fresh as a vegetable and the seeds and flowers are used as spices (Nuez and Hernández Bermejo, 1994). It is consumed as a raw green, as a part of salad mixes, as a cooked green, and is now very popular as a pizza topping (Padulosi, 1995; Padulosi and Pignone, 1997). Garden rocket is one of the basic ingredients in Sudanese green salad dish. It has many uses other than food. On the Indian subcontinent, special ecotypes of garden rocket are cultivated for seed production and subsequent oil extraction (Bhandari and Chandel, 1997). Garden rocket is believed to have aphrodisiac properties (Padulosi, 1995). It contains glycosides, mineral salts and vitamin C and is therefore considered to be an excellent stomachic stimulant, and is also used as a diuretic and anti-scorbutic (Nuez and Hernández Bermejo, 1994). Recent studies showed that an extract from rocket leaves possess anti-secretory, cyto-protective and anti-ulcer activities (Alqasoumi *et al.*, 2009).

Work on soil salinity in the Sudan may be traced back to the turn of the last century, when it was established by the early work of Beam (1911) who found that there were potential salinity and alkalinity hazards associated with the soil of the Gezira Scheme.

The soils of northern Sudan are affected to a greater degree by soil salinity, particularly from Khartoum northwards along both banks of the Nile (Drover, 1966). The area affected by salinity in Sudan can hardly be estimated since few systematic surveys have been made. However, the areas which are potentially irrigatable but where salinity is the main limiting factor for its development cover more than 200,000 ha (Karouri, 1967).

The area south of Khartoum between the blue and the White Niles and extending as far south as the northwest boundary of the Gezira Scheme is predominantly saline and/or sodic soil, the total area being estimated at 81,000 ha. Due to salinity problems this area has never been utilized agriculturally in any form except for short-lived animal fattening scheme which was established in an area of 4,000 ha. Low productivity of the land was one of the factors that contributed to its failure (Balls, 1935).

Ground water is an important resource of irrigation in Sudan. About 80% of the inhabitants of Sudan depend on ground water for their living most of the year (Wheater, 2007). Ground water constituents are greatly affected by many factors including intensive evaporation of effluent surface irrigation water that led to the precipitation of evaporates, especially affecting the ground water at shallow depth (Subyani, 2005), local hydro geological conditions and the chemical makeup of minerals. Some chemicals are more soluble than others, making them more likely to become dissolved in water (Harrington *et al.*, 2008). Proximity of ground water to seacoast (Nassereddin and Mimi, 2005) and direct contact of seawater to the aquifers (Shaaban, 2001), internal movement of ground water (Mehta *et al*., 2000), increase of ground water discharge increases ground water salinity (Munday and Andrew, 2008). The continuous changes in ground water chemical constituents necessitate a frequent examination of ground water quality before being used for irrigation or other purposes.

Water quality refers to the characteristics of water supply that influence its sustainability for specific use. Quality is defined by certain physical, chemical and biological characteristics (Ayers and Wescot, 1989). Water quality can also be assessed by of quantitative analysis, such as pH and Electrical conductivity (EC) (Ayers and Wescot, 1989). Scherer *et al*. (1996) reported that water quality for irrigation purposes is determined by its salt content, cations (calcium, magnesium) and anions (bicarbonates, carbonates, sulfate and chloride). Plants have different responses to water quality problem; some crops can produce acceptable yield at much greater salinity than others (Ayers and Wescot, 1989). Selecting more tolerant crops offers a very practical solution to salinity and toxicity (Ayers and Wescot, 1989). Crop suitability for reuse systems however, will depend on the production potential under saline-sodic conditions (Grattan, 2004).

Salinity problems in some soils and sources of water in Sudan led to reduction in productivity and hence, agricultural activity in some areas. This problem can be counteracted by selecting crop plants that can tolerate salinity of water and/or soil or by addressing the source of the problem (salinity).

This study was conducted to investigate the effects of salinity in irrigation water on seed germination and the vegetative and reproductive growth of garden rocket (*Eruca sativa* Mill.), an important vegetable crop in Sudan.

CHAPTER TWO

LITERATURE REVIEW

Garden Rocket (*Eruca sativa* Mill.):

Garden rocket (*Eruca sativa* Mill.) belongs to the mustard family Brassicaceae (Cruciferae) the class Magnoliopsida (Dicotyledonae) and the flowering plants (Angiosperms) Division Magnoliophyta.

The origin of garden rocket is believed to be the Mediterranean Basin and West Asia. It is a herbal plant with an annual root of the sphenoid, and short stem before flowering. At flowering, it ranges in length from 30 to 75 cm carrying the leaves in a crammed opposite position. The leaves swell when budding and branching and bearing flowers, and have long leaf necks. The leaves are smooth, oval and lobed into three lobes. The upper lobe is greater than the two sides lobes. Flowers are complete, white or yellow in colour. Fruits, simple dry silique, are small and white in colour. Seeds are also small and dark gray in color. Two varieties of garden rocket are known in Sudan: Baladi and Egyptian varieties.

Planting:

Garden rocket in Sudan is grown on year-round basis. It is largely grown in the winter and fall seasons. High temperatures in the summer season lead to early plant flowering, which affects the productivity and quality of the crop. Garden rocket is grown in all kinds of soils but gives a rich harvest in fertile loam soil.

The soil is plowed and soften, then is divided into tubs and irrigated before planting in order to conduct the resurfacing and give an opportunity for the germination of seeds of weeds which are then removed.

The seeds of garden rocket are dispersed at a rate of 6-8 kg/fed. The seeds are relatively small thus they are usually mixed with sand to ensure good distribution in the target area. The seeds are covered by hands with a layer of soil and then irrigated. When cultivated in fertile loam soils, no fertilizer is needed to the planted crop. But when planted in sandy soils or light and heavy clays compost or animal manure is usually added at a rate of 10 tons/fed after plowing, or a dose of the chemical fertilizer ammonium sulfate at a rate of 50 kg/fed is added after a week from planting.

Harvesting:

In the summer crops, the leaves are harvested once from the roots after about three weeks from planting. But in the winter crops three harvests can be obtained from the crop. Total productivity ranges between 5 and 10 tons per fed. depending on the fertility, planting season and number of cutting intervals. Garden rocket is infected by cotton leaf worm and leaf miner, but these insects do not cause economic damage to the crop. The leaves are stored at 7-10 °C and 90-95 % relative humidity for two weeks.

Salinity and Salt Stress:

A salt is a combination of positively charged elements (cations) and negatively charged elements (anions). Cations include calcium, magnesium, sodium and potassium. Anions that will dissolve in water include carbonate, bicarbonate, nitrate, sulfate, chloride and boron. The measurements of salinity include: electrical conductivity (EC), total dissolved solids (TDS), acidity (pH), carbonate hardness (CH), total hardness (TH), and sodium-adsorption ratio (SAR).

Soluble salts levels are measured by an instrument called a solubridge. This instrument measures EC in millimohs per centimeter (mmohs cm^{-1}) or deci Siemens per meter (dS m^{-1}).

World-wide, one of the most severe problems in crop production is caused by excess salts in the soil. A similar problem is frequently encountered in media for container-grown nursery and greenhouse plants.

Salinity is a major environmental constraint to crop productivity throughout the arid and semi-arid regions of the world (Foolad and Lin, 1997). It has reached a level of 19.5% of all irrigated land and 2.1% of dry land (FAO, 2005). Salinity affects 7% of the world’s land area, which amounts to 930 million ha (Szabolcs, 1994). Soluble salts problems may be the result of an inherently high level of salts in the soil, use of saline irrigation water, application of excessive amounts of fertilizers, or all three causes. Rain, tornadoes, and wind also add salts to coastal agricultural land. If measures are not taken to reduce salt buildup in soils repeatedly irrigated with saline water, yields will be reduced and the land may eventually have to be removed from production. Salt accumulation due to flood irrigation caused low food yields and may have been a major factor in bringing the Roman Empire to its knees.

Ayers (1997) reported that most water quality guidelines on crop productivity are mainly on the water salinity hazard as measured by electrical conductivity (ECw). The primary effect of high ECw on crop productivity is the inability of the plant to compete with ions in the soil solution for water. This is usually referred to as physiological drought for plants. The amount of water transpired through a crop is directly related to yield. Therefore, irrigation water with high ECw reduces yield potential. In addition, salinity could impose a toxic effect on plants.

Most crops are salt sensitive or hypersensitive plants (glycophytes) in contrast to halophytes, which are native flora of saline environments. Some halophytes have the capacity to accommodate extreme salinity because of very special anatomical and morphological adaptations or avoidance mechanisms (Flowers *et al.,* 1986). Alan (1994) reported that plants vary in their response to soil salinity. Salt tolerant plants (plants that are less affected by salinity) are better able to adjust internally to the osmotic effects of high salt concentrations than salt-sensitive plants. Salt-tolerant plants are more able to absorb water from saline soils, while salt-sensitive plants have limited ability to adjust and are injured at relatively low salt concentrations. Many horticultural and field crops are classified as sensitive or moderately sensitive to soil salinity (Bauder *et al.,* 2007).

Salt stress and dehydration stress show a high degree of similarity with respect to physiological, biochemical, molecular and genetical effects (Cushman *et al.*, 1990). This is possibly due to the fact that sub-lethal salt-stress condition is ultimately an osmotic effect, which is apparently similar to that brought in by water deficit and to some extent by cold as well as heat stresses (Almoguera *et al*., 1995). High salinity causes hyper-osmotic stress and ion disequilibrium that produce secondary effects or pathologies (Hasegawa *et al.,* 2000; Zhu, 2001).

Fundamentally, plants cope by either avoiding or tolerating salt stress. That is, plants are either dormant during the salt episode or there must be cellular adjustment to tolerate the saline environment. Tolerance mechanisms can be categorized as those that function to minimize osmotic stress or ion disequilibrium or alleviate the consequent secondary effects caused by these stresses.

The chemical potential of the saline solution initially establishes a water potential imbalance between the apoplast and symplast that leads to turgor decrease, which if severe enough can cause growth reduction (Bohnert *et al.,* 1995). Growth cessation occurs when turgor is reduced below the yield threshold of the cell wall. Cellular dehydration begins when the water potential difference is greater than can be compensated for by turgor loss (Taiz and Zeiger, 1998).

Sodium Hazards:

Sodium hazard (or alkalinity hazard) in the use of water for irrigation is determined by the absolute and relative concentration of sodium (Na+) to calcium (Ca++) and magnesium (Mg++) ions in a water sample and it is expressed as Sodium Adsorbed Ratio (SAR) which is the measure of sodium hazard in irrigation water (Silva, 2004;Siamak and Srikantaswamy, 2008). Excess sodium in water produces undesirable effects on soil properties and reduces soil permeability (Dhirendra *et al.*, 2009). Sodium, when replacing adsorbed calcium and magnesium becomes hazardous as it causes damage to the soil, making it to be compact and impervious, especially the soil structure, resulting in the formation of crusts, water-logging, reduced aeration and infiltration rate. Excess Na+ ions in soil may also be toxic to certain types of crops (Tiwari and Manzoor, 1988; Nata *et al.*, 2009; Ogunfowokan *et al.*, 2009; 2013).

Chlorides:

Although chloride is an essential element to plants in very low concentrations, it can cause toxicity to sensitive crops at high concentrations. Like sodium, high chloride concentrations cause more problems when applied with sprinkler irrigation (Mass, 1990). Leaf burn under sprinkler from both sodium and chloride can be reduced by night time irrigation or on cool, cloudy days. Drop nozzles and drag hoses are also recommended when applying any saline irrigation water through a sprinkler system to avoid direct contact with leaf surfaces (Mass, 1990).

Irrigation Water Quality:

According to Biernbaum (1994), both irrigation water quality and proper irrigation management are critical to successful crop production. Irrigation water of poor quality, can have a detrimental effect on plant growth, for example poor irrigation water quality with excess salts can damage plants in various ways, but the most common problems are caused by salts affecting osmotic relationship between the roots and the soil moisture (Malash *et al*., 2005).

The quality of the irrigation water may affect both crop yields and soil physical conditions, even if all other conditions and cultural practices are favourable or optimal. Different crops require different irrigation water qualities; therefore, testing the irrigation water prior to selecting the site and the crops to be grown is critical (Shahinasi and Kashuta, 2008).

Effects of Salinity on Plants:

The general effect of salinity is reduction of the growth rate resulting in smaller leaves, shorter stature, and sometimes fewer leaves. The initial and primary effect of salinity, especially at low to moderate concentrations, is due to its osmotic effects (Munns and Termaat, 1986; Jacoby, 1994). Roots are also reduced in length and mass and may become thinner or thicker. Maturity rate may be delayed or advanced depending on species. The degree to which growth is reduced by salinity differs greatly with species and to a lesser extent with varieties within a species. The severity of salinity response is also mediated by environmental interactions such as relative humidity, temperature, radiation and air pollution (Shannon *et al*., 1994). Depending upon the composition of the saline solution, ion toxicities or nutritional deficiencies may arise because of a predominance of a specific ion or competition effects among cations or anions (Bernstein *et al.*, 1974). The osmotic effects of salinity contribute to reduced growth rate, changes in leaf colour, and developmental characteristics such as root/shoot ratio and maturity rate. Ionic effects are manifested more generally in leaf and meristem damage or as symptoms typical of nutritional disorders. Thus, high concentrations of $Na+$ or Cl^- may accumulate in leaves or portions of leaves and result in `scorching' or `firing' of leaves; whereas, nutritional deficiency symptoms are generally similar to those that occur in the absence of salinity. Calcium deficiency symptoms are common when Na/Ca ratio is high in soil water.

All salinity effects may not be negative; salinity may have some favorable effects on yield, quality, and on disease resistance. In spinach, for example, yields may initially increase at low to moderate salinity (Osawa, 1963). Sugar contents increase in carrot and starch content decreases in potatoes as salinity increases (Bernstein, 1959); cabbage heads are more solid at low salinity levels, but are less compact as salinity increases (Osawa, 1961). Celery has been reported to be both more resistant and more susceptible to blackheart (Osawa, 1963; Aloni and Pressman, 1987) at moderate or high salinity. These and other effects will be covered herein in more detail as they relate to the salt tolerance of specific vegetable plant species including garden rocket.

Brassicaceae (cabbage, broccoli, cauliflower, mustards, radish, and kale)

Kale (*B. oleracea,* Acephala group)

Kale is very closely related to the cabbage, but instead of forming a compact head, it is open-leaved and the leaves arise from a simple, erect, stout stem. Kale appears to be the oldest variety of *Brassica* (Brouk, 1975). There is little information concerning the salt tolerance of kale, although Malcolm and Smith (1971) suggested that the crop may be productive when irrigated with waters that have electrical conductivities in the range of 2.3 to 5.5 dS/m^{-1}.

Broccoli (*B. oleracea*, Botrytis group)

Typically, broccoli produces small, loose heads that develop from buds in the leaf axils of both the central stem and side-shoots. Stems of broccoli are much thinner and longer than those of cauliflower, so that most of the edible part is formed by the broccoli stalks, in contrast to cauliflower which is formed mainly from fleshy flowers (Brouk, 1975). Broccoli is a moderately salt sensitive crop with an estimated threshold EC of 2.8 dS/m^{-1} and a slope of 9.2% for each unit increase in salinity (Bernstein *et al*., 1974).

Cauliflower (*B. oleracea*, Botrytis group)

Cauliflower appears to be native to Asia Minor and was known in Europe in the 16th century, as evidenced by its oldest know description in a book published in 1559 by the Dutch botanist, Dodoeus. The edible part of the plant is the solid head formed by the racemose inflorescence composed of abortive flowers whose stalks are short, fleshy, and closely crowded. The crop has been rated as moderately salt tolerant (Bernstein, 1959) but little quantitative data is available.

Cabbage (*B. oleracea*, Capitata group)

Cabbage has been cultivated for at least 2000 to 2500 years. The smooth, fleshy leaves appear on a shortened stem and form a compact, hard head. Yield, as measured by head weight, is rated as moderately sensitive to salinity (Bernstein and Ayers, 1949; Osawa, 1965; Bernstein *et al.*, 1974). The threshold salinity is 1.8 dS/m^{-1} (ECe) with a slope of 9.7% per dS/m^{-1}. Under salt stress, cabbage heads are generally more compact, and leaves are fleshier than under no saline conditions.

Mustard greens (*B. juncea (L.)* Czern. and Coss.)

The salt tolerance of *B. juncea* has been reported by numerous investigators (Jain *et al.*, 1990; Ashraf and Naqvi, 1992). However, the research emphasis has been on Indian or brown mustard (*B. juncea* Czern. and Coss.), a crop valued for its seed oil production (Ashraf and McNeilly, 1990; Sharma and Gill, 1994). Little, if any, information is available on the effects of salinity on those leafy mustard varieties that are important and popular specialties in cuisines worldwide. Depending upon variety, leaves may be distinctively shaped (broadly oval or narrow and deeply notched) and highly colored (bright green, purple, or brownish red). Shoot weight of *B. juncea* decreased to less than 50% of the non-salinized controls when plants were grown in solution cultures at 50 mM NaCl (Ashraf and McNeilly, 1990). A great amount of variability exists among cultivars. Irrigation of five cultivars of *B. juncea* with 100 mM NaCl solutions in sand cultures for 4 weeks resulted in relative decreases in shoot growth from as little as 28% to as much as 72% (Ashraf, 1992).

Garden rocket (*Eruca sativa* Mill.)

Eruca sativa is probably native to southern Europe and western Asia. It is often found growing in arid and semiarid regions and on severely salt-affected soils (Deo and Lal, 1982; Ashraf and Noor, 1993). Relative salt tolerance and ion relations of two *E. sativa* genotypes were compared with *Brassica carinata* or Ethiopian mustard (Ashraf and Noor, 1993). The yield and relative growth rate of the *Eruca* line collected from a salt-affected field was superior to the normal line as well as to Ethiopian mustard. The salt tolerance of the former line appears to be associated with exclusion of Na+, high K/Na selectivity and high Ca2+ uptake. Ashraf (1994) extended the comparison of the two populations of *Eruca* by investigating the role of soluble sugars, proline, free amino acids, and soluble proteins in relative salt tolerance. The tolerant line accumulated significantly higher amounts of sugars, proline, and amino acids in leaves than the non-tolerant population. However, the genotypes did not differ in soluble protein content. The G50 reduction in vegetative growth of the tolerant line occurred at about 300 mM NaCl (EC= 30 dS m^{-1}) in salinized sand cultures.

Radish (*Raphanus sativus* L.)

Radish probably originated in western Asia. It was cultivated 4500 years ago in Egypt and Assyria, and spread at least 2000 years ago to China. Many cultivars of radish exist, including the large daikon. The most popular variety, radicula, may be spherical, about 2 cm in diameter or long (6-7 cm). The edible part is the swollen hypocotyl. Radish is a salt-sensitive crop (Osawa, 1965; Malcolm and Smith, 1971). Hoffman and Rawlins, (1971) studied the interactive effects of salinity and relative humidity on radish yield and found that when the crop was grown under low RH (45%), root yield declined 13% per dS/m^{-1} when salinity exceeded a threshold of 1.3 dS/m^{-1}. However, at high RH (90%) the salt tolerance threshold was increased to about 5.2 dS/m^{-1} with no change in the slope. Scialabba and Melati (1990) demonstrated that NaCl salinity caused a lack of coordination between cellular expansion and differentiation in radish seedlings. As salinity increased, structural and cellular modifications, in the form of wall thickening and metabolic aggregates inside parenchyma cells were evident. The stage of growth at which seedlings are salt-stressed can be identified by an ontogenetic study of xylem elements. Previously, it had been noted that salinity differentially inhibited growth of different root types in radish (Waisel and Breckle, 1987). Lateral root growth was most sensitive; whereas, the initiation of new laterals was most tolerant. The G50 for radish as determined in NaCl solutions may be anywhere from 14 to 30 dS/m^{-1} (Shadded and Zidan, 1989; Scialabba and Melati, 1990).

CHAPTER THREE

MATERIALS AND METHODS

This study was carried out during the period of 10/2015-2/2016 at the Tissue Culture Laboratory complex, Department of Horticulture, College of Agricultural Studies, Sudan University of Science and Technology, Shambat, with the objective of determining salinity tolerance of garden rocket.

Garden rocket seeds were purchased from the Central Market, Khartoum North, washed under running tap water, dried and stored under ambient room temperature, in polyethylene bags until used. The seeds were given no pretreatment of any kind. Four hundred seeds were visually selected for the first experiment on the basis of size uniformity to minimize potential seed size effects. The effect of five concentrations of sodium chloride (NaCl) solution on germination, seedling growth and the vegetative and reproductive growth was studied. In all experiments the treatments comprised:

1. Distilled water as a control.
2. 0.01 M Sodium chloride solution.
3. 0.02 M Sodium chloride solution.
4. 0.10 M Sodium chloride solution.
5. 0.13 M Sodium chloride solution.

and having the following characterics:

Solution concentration		Water potential	Electrical conductivity
(M)	(ppm)	(- mPa)	(ds/m^{-1})
0.00	0000	0.00	00.009
0.02	1169	0.10	02.450
0.03	1753	0.15	04.900
0.10	5844	0.50	09.280
0.13	7598	0.64	17.000

In the first experiment the effect of the five treatment concentrations on the germination of garden rocket seeds was studied. Twenty seeds were placed on a filter paper wetted by the corresponding test solution in a Petri dish and then the test solutions (treatments) were applied. A total of 400 seeds were used (20X4X5=400 seeds) in this experiment. The seeds were examined daily for germination. A seed was considered to have germinated when the radicle emerged through the seed coat and was visible to the naked eye. Final germination percentage was recorded when no germination was detected for three successive days.

In the second experiment garden rocket seeds were germinated on water wetted filter paper in a Petri dish. Two germinated seeds were transferred to each Petri dish containing a filter paper and the treatment solutions were applied to determine the effect of salt concentration on the early growth of garden rocket seedlings. Each treatment was replicated four times. The data collected were length of radicle and plumule.

About two ml of solution were added in each Petri dish (replicate) in the first and second experiment and the two experiments were carried out at room temperature of about 20 ºC.

In experiment three garden rocket seeds were planted in each plastic pot of 9×12 cm dimension containing 794 g of clay soil. The germinating seedlings were thinned to one seedling after three days from germination. The seedlings were irrigated with tap water for a period of two weeks from germination. After that the seedlings were irrigated regularly with the appropriate test solution. This experiment was carried out under lath house conditions with the mean temperatures of about 36°C. The number of leaves, flowers and fruits and length of stem were recorded.

In all three experiments a completely randomized design (CRD) was used with each treatment replicated four times, and each experiment was repeated three times. Data collected were subjected to analysis of variance (ANOVA) appropriate for completely randomized design. All statistical analyses were performed using Mstat-C program computer package and Duncan’s Multiple Range Test was used to separate treatment means.

CHAPTER FOUR

RESULTS AND DISCUSSION

Table 1 displays the data of the effects of the control and the sodium chloride (NaCl) concentrations on seed germination of garden rocket. The germination percentages were very high, above 90 % for all treatments with the exception of the highest concentration which was 88%. All salt concentrations tested did not negatively affect the germination percentage compared with the control as no significant difference among treatments tested was obtained. The seeds of the plants depend on food reserve in the cotyledons for satisfying their requirement for germination and only need an exogenous source of water for the resumption of growth of the embryo. It is most probable that water absorption by the seed coat was not affected by the concentrations of the solutions in the germination test. It is also possible that the concentrations of the salt tested were within the range that seed germination of garden rocket could tolerate. The germination rate, also, was not detrimentally affected by any of the sodium chloride solution, as evaluated by both the germination rate index (GRI) and the corrected germination rate index (CGRI) (Table1). Both these indices were used to evaluate the germination rate in biological terms (Hsu *et al.*, 1985). It seems that the seeds were very viable and well selected before used in the experiments. Probably, the seeds were harvested during the current season and the plants were well taken care of and the environmental conditions were perfect for seed production of this plant species. Such high final germination percentage and germination rate were usually associated with the seeds that germinate within 48 hours in incubation. Such seeds are usually small in size and seems to be adapted to fast germination. Moreover, the seeds often have a very low water potential compared to other plant parts. Hence, the seeds would be imbibed at high ECw, whereas the other plant parts would not.

As shown in Table 2 and Fig.1 the radicle length of the germinated seeds of garden rocket was gradually decreased by increasing NaCl concentration. With the exception of the 0.02M solution treatment, all the concentration treatments significantly decreased radicle length relative to the control. However, these were not significantly different from each other. This showed that radicle length is highly more sensitive to salinity than seed germination.

The length of the plumule showed more tolerance to salinity compared to the radicle, where no significant reduction in length was obtained up to the 0.03M salt concentration tested. Higher concentrations were, however not significantly different from each other (Table2\Fig.2). The length of the radicle was more negatively affected than the plumule by other stresses such as the allelochemicals effects on the growth of mesquite (*Prosopis juliflora*) (Warrag, 1995) and bermuda grass (*Cynodan dactylon*) (Al-Humaid and Warrag, 1999) and lettuce (*Lactuca sativa*) (Warrag and Warrag, 2011).

The data depicted in Table 3 and Fig.3 showed the length of leaves and Table 3 showed the number of leaves and length of the stems of garden rocket plants as affected by NaCl concentrations. All NaCl concentrations tested had no significant effect on leaf number but leaf length was progressively decreased with increasing the salt concentration with the 0.10 and 0.13 M treatments, being more deleterious than the control. This indicates that leaf formation was unresponsive to salt concentrations used, whereas the leaf length seems to be so.

The length of the stem of garden rocket was not affected by the two lowest concentrations of NaCl tested giving non-significant values relative to the control. The two highest concentrations of the salt tested, on the other hand, resulted in highly significant reduction in the length of the stem compared to the treatments tested indicating the relatively high sensitivity of length of stems of garden rocket to salinity. The plants usually respond to high salinity by stunting growth, since the cells seems to be less turgid. Hence, no growth would have occurred (Bohnert *et al.*, 1995).

There was no significant difference in the number of flowers per plant was obtained between the control and the two lowest salt concentrations (0.02M and 0.03M) (Table 4). Flower formation declined sharply by the 0.10 M with a significant difference from the other salt concentrations and the control. The highest salt concentration completely inhibited flower formation (Table 4). For the effects of NaCl concentration on number of fruits formed by garden rocket plants, the two lowest salt concentrations decreased fruit formation with a significant difference compared to the control (Table 4). Fruit formation was, however, completely inhibited by the two highest salt concentrations. These results indicate that fruit formation is more sensitive to salts than flower formation probably through the effect of salts on male sterility, pollen tube growth and/or fertilization and consequently fruit set. It is also possible that the food reserves in the plant tissues are not adequate in quantity and quality for fruit set and development. Male sterility is responsible for the failure of fruit set (flower abscission) in many plant species (Warrag and Hall, 1983).

All these negative effects were most probably due to higher osmotic potential of the saline solution resulting in physiological drought and/or due to toxicity problem.

Development of salinity-tolerant cultivars is essential for sustaining agricultural production. However, with a few exceptions, conventional breeding techniques have been unsuccessful in transferring salt tolerance. This can be attributed to the poor understanding of the molecular mechanisms associated with salt tolerance. Thus, understanding the molecular basis of salt tolerance will be helpful in developing selection strategies for improving the growth of plants in salt environments.

Table 1. Effect of sodium chloride (NaCl) concentration on the final seed germination (%), germination rate index (GRI) and corrected germination rate index (CGRI) of garden rocket plants.

NaCl concentration (M)	Final Germination (%)	GRI (day^{-1})	CGRI (day^{-1})
0.00	94.24a*	89.47a	95.23a
0.02	94.24a	88.49a	94.24a
0.03	99.99a	95.22a	95.23a
0.10	94.24a	84.69a	90.45a
0.13	88.49a	88.52a	95.17a
LSD	21.01	23.64	20.19

*Means in a column followed by the same letter are not significantly different at P= 0.05, according to Duncan's multiple range test.

Table 2. Effect of sodium chloride (NaCl) concentration on radicle and plumule length 6 days from germination of garden rocket plants.

NaCl concentration (M)	Radicle length (cm)	Plumule length (cm)
0.00	0.83a*	1.43a
0.02	0.73ab	1.39a
0.03	0.53bc	1.23ab
0.10	0.35c	0.95bc
0.13	0.33c	0.80c
LSD	0.26	0.38

*Means in a column followed by the same letters are not significantly different at P= 0.05, according to Duncan’s multiple range test.

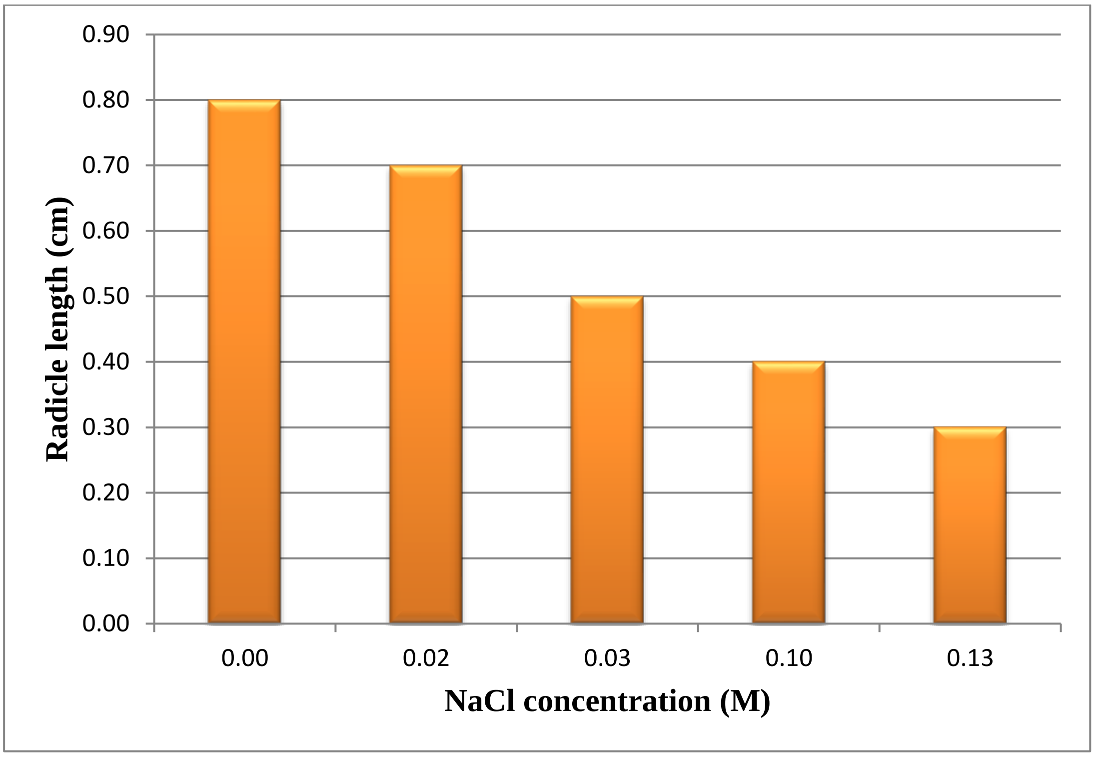

Figure 1. Effect of sodium chloride (NaCl) concentration on radicle length (cm) 6 days from germination.

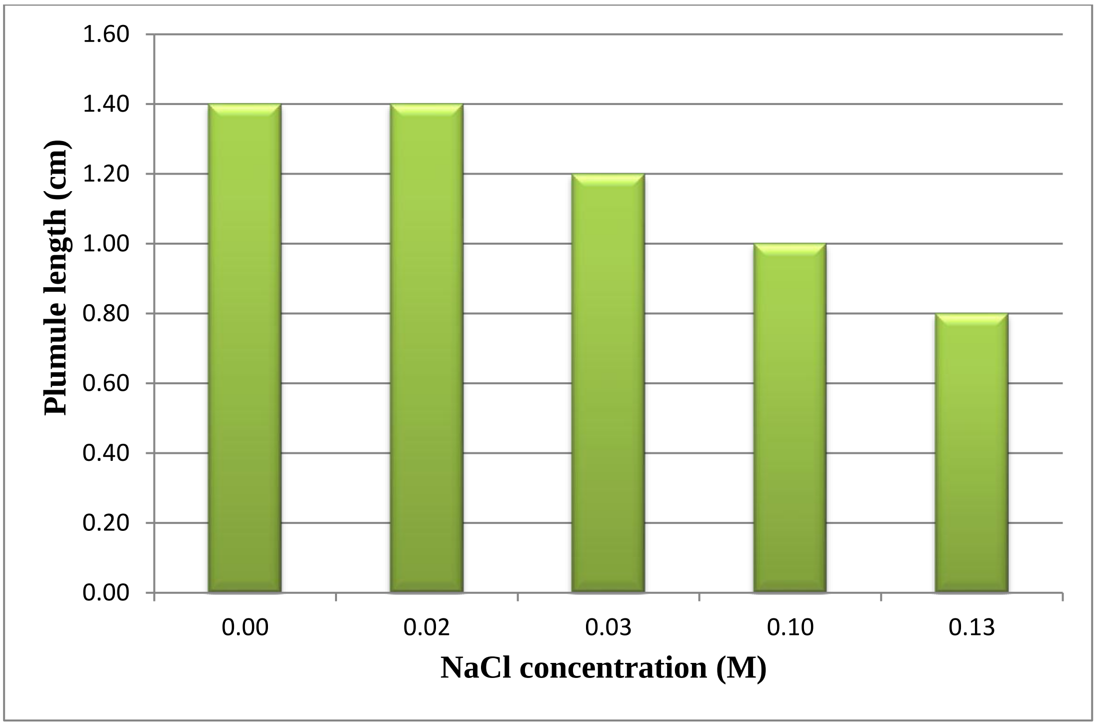

Figure 2. Effect of sodium chloride (NaCl) concentrations on plumule length (cm) 6 days from germination.

Table 3. Effect of sodium chloride (NaCl) concentration on number and length of leaves and stems of garden rocket plants.

NaCl concentration (M)	No. of leaves per plant	Leaf length (cm)	Stem length (cm)
0.00	6.00a*	6.13a	52.05a
0.02	6.25a	7.45ab	54.13a
0.03	5.75a	4.80abc	44.38a
0.10	5.25a	3.60bc	21.93b
0.13	4.75a	2.33c	2.38c
LSD	1.52	2.99	15.26

*Means in a column followed by the same letters are not significantly different at P= 0.05, according to Duncan's multiple range test.

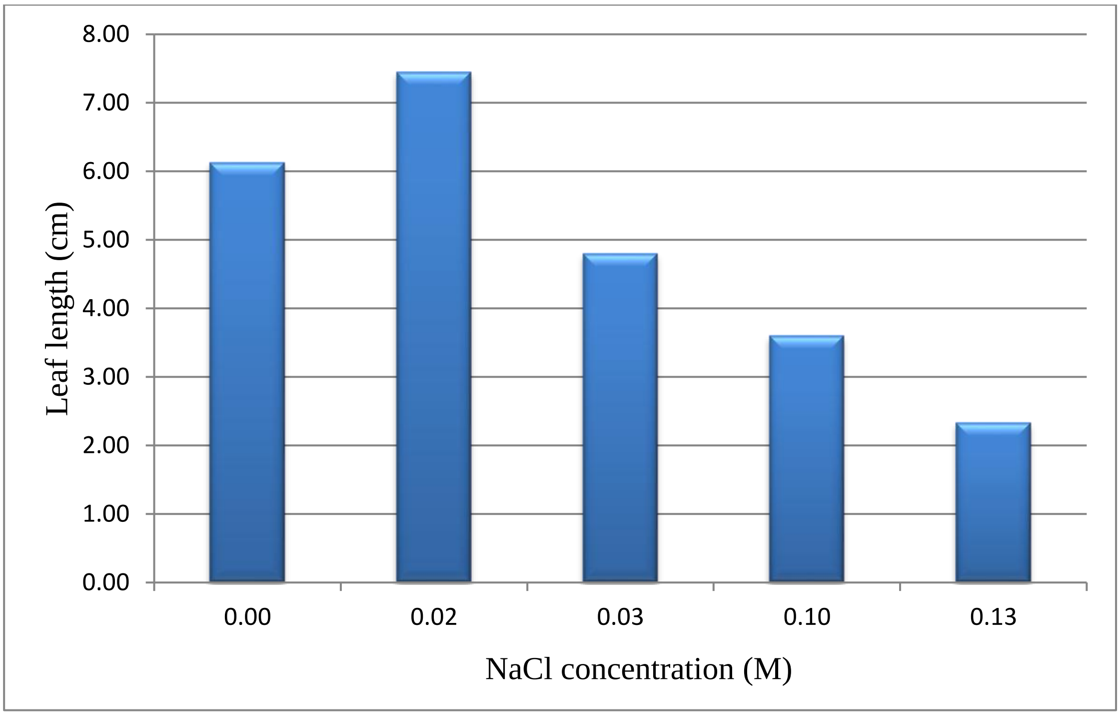

Figure 3. Effect of sodium chloride (NaCl) concentrations on leaf length after 30 days from sowing.

Table 4. Effect of sodium chloride (NaCl) concentration on number of flowers, number of fruits, per plant and fruit set (%) of garden rocket plants.

NaCl concentration (M)	No. of flowers per plant	No. of fruits per plant	Fruit set (%)
0.00	18.00a*	15.75a	87.50
0.02	12.25a	10.50a	85.71
0.03	12.75a	12.00a	94.12
0.10	3.50b	1.00b	28.57
0.13	0.00b	0.00b	0.000
LSD	7.18	7.48	

*Means in a column followed by the same letter are not significantly different at P= 0.05, according to Duncan's multiple range test.

CONCLUSION

The response of garden rocket (*Eruca sativa* Mill.) showed that all the sodium chloride (NaCl) solution concentrations (0.02, 0.03, 0.10, 0.13 M) had no significant negative effect on the final germination percentage and the germination rate, as evaluated by the germination rate index and the corrected germination rate index, compared to the distilled water control. However, the radicle and the plumule elongation were reduced by the two highest concentrations. Likewise were the number of leaves and flowers, stem length and fruit set. These negative effects could be attributed to the osmotic and/or toxic effects of salinity. Hence, saline environments should be avoided for growing garden rocket until finding salinity tolerant genotypes that have mechanisms to minimize the osmotic stress and/or ion toxicity or alleviate the consequent secondary effects caused by these stresses.

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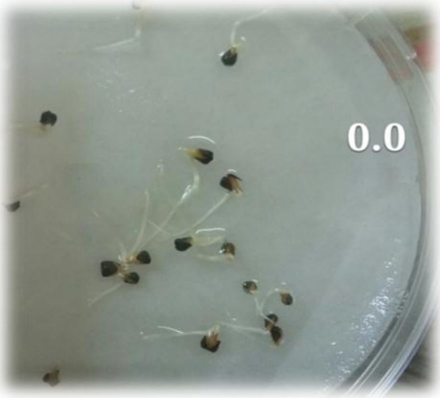
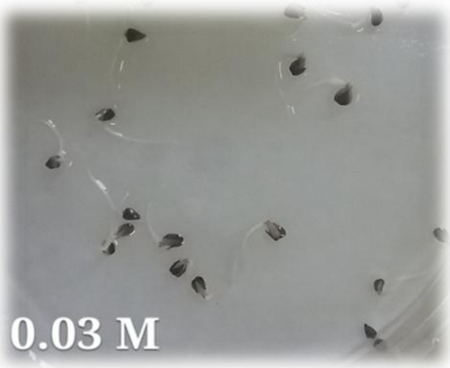
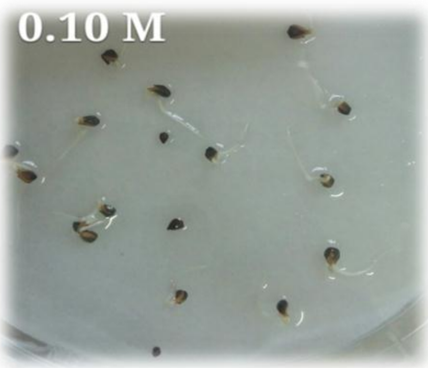
Appendix 1

- The effect of sodium chloride (NaCl) concentration on seed germination.

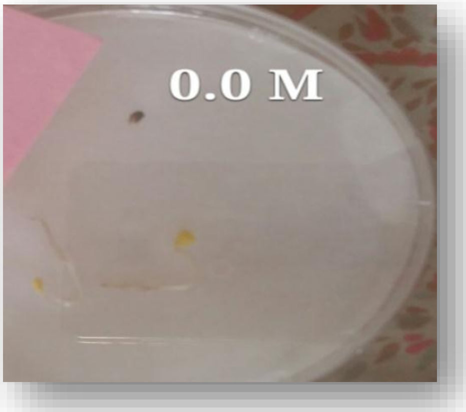


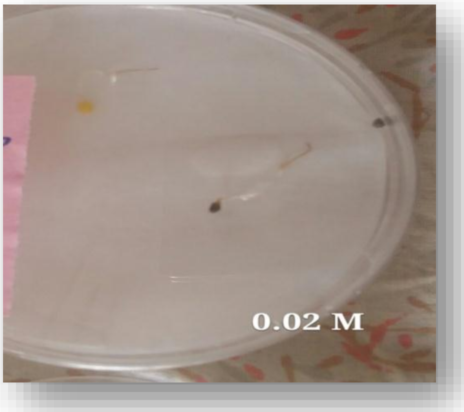


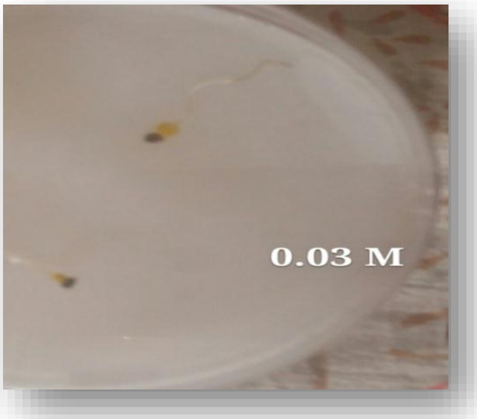


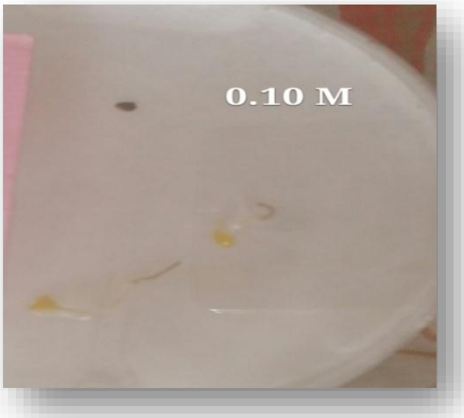
Appendix 2

- Effect of sodium chloride (NaCl) concentration on radicle and plumule length.









Appendix 3

- Effect of sodium chloride (NaCl) concentration on garden rocket plants.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