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Effects of salinity stress on growth, Water use efficiency and biomass partitioning of *Vernonia hymenolepis* in screenhouse potted soil amended with NPK 20:10:10

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Abstract

Future crop production is predicted to face significant challenges from salinity stress due to secondary salinization. Therefore future-proofing crop production in these conditions is an essential path towards addressing food security. We evaluated the effect of irrigation with water of 0, 4 and 8 ppt salinity on growth, biomass partitioning, WUE and chlorophyll fluorescence of *Vernonia hymenolepis* A.Rich as ameliorated by fertilization with three levels of NPK20:10:10. Data were analysed for variance using the General Linear Model ANOVA procedure, after positive tests for normality and homogeneity of variance. Means were separated through the Dunnett test. Pearson Correlation was done to determine relationship between variables and these were spatially projected using the Factor Analysis procedure, without rotation. Under fertilization at 8 g NPK20:10:10 per plant, growth was stimulated by salinity increase to 4 ppt (35.43cm) compared to 30.43cm for control plants. Fertilizer application significantly improved all the biomass fractions of plants irrigated with water of 4 ppt relative to the control, while root:shoot ratios were highest for unfertilized plants indicating resource re-allocation to roots for better foraging. Chlorophyll fluorescence ranged between 0.716 and 0.727 and did not differ significantly across treatments. These values indicate that all treatments were under stress, including control plants. Values of WUE and RGR indicate that fertilization of plants irrigated with water of 4ppt salinity enhances growth and Harvest Index of *V. hymenolepis,* in spite of the registered stress. This is significant to future food security.

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Introduction

Efficient crop production in the future is a priority fraught with challenges. This is because the future environment is predicted to change significantly. For good crop growth and yield, the plant interacts with the environment. Environmental parameters like soil conditions, temperature, light, relative humidity and water availability interact with plant varietal characteristics to determine the eventual growth and yield of the crop (Asseng *et al*., 2015; Aggarwal, 2009). Of these environmental conditions, water availability could be the single most important consideration in crop production systems, especially water in the root zone of plants (Rossato *et al*., 2017). This is especially true when producing in fringe lands, in the off-season or in periods of sparse rainfall, when irrigation becomes indispensable to crop production (Siebert and Döll, 2010; Postel, 1998). Such unstable water scenarios for crop production can be expected under several climate change scenarios (Mo *et al*., 2017; Xia *et al*., 2017).

As farmers turn to irrigation, a second constraint is the availability of suitable water resources for irrigation. With reducing freshwater resources, crop lands are increasingly irrigated with water from doubtful sources (Majeed and Siyyar, 2020). A consequence of using poor quality water for irrigation is secondary salinization of the soil (Postel, 1998). Soil salinity refers to the dissolved inorganic salt content of the soil, and salinity stress in plants refers to altered morphology, physiology, reproduction etc. as a result of accumulation of Na+ and Cl- ions in tissues of plants exposed to high NaCl concentrations. Secondary salinization has been shown to result from several anthropogenic activities including irrigated agriculture (Cuevas *et al*., 2019; Shrivastava and Kumar, 2015). In the soil, salinity fixes nutrients and makes them unavailable to plants. It also affects the solute potential of soil water, making uptake more ATP-costly. Plants growing in saline conditions must therefore be adapted to these conditions. They develop both physiological and morphological strategies to cope with salt stress. Physiologically, compatible osmolytes such as glycinebetaine and proline are formed to stabilize membranes, DNA and proteins aid in water balance; ion accumulation, salt secretion and compartmentalization are other strategies to adjust the water balance within the plants (Tabot *et al*., 2018; El-RheemKh and Zaki, 2017; Wu *et al*., 2015; Tabot and Adams, 2014; Athar and Ashraf, 2009). Morphologically, some tolerant plants develop hydathodes and/or salt glands through which excess salts are secreted to the outside, thereby maintaining normal levels of cytosolic concentrations (Volkov and Beilby, 2017; Maathuis *et al*., 2014; Tabot and Adams, 2014) . There is a shift in biomass accumulation such that the root architecture is increased relative to the shoot, for better foraging for water and fixed nutrients (Acosta-Motos *et al*., 2017). Overall growth reduction typically results because the physiological and morphological adjustments needed for stress survival also require significant ATP and diversion of photosynthate from growth and reproduction, as well as direct limitation of the photosynthetic process through stomatal conductance control (Aslam *et al*., 2017).

On the other hand, susceptible plants would simply not grow, and will most often die under the effects of the stress. If this results in a cropland the loses would be significant with ramifications well beyond the farm level (Porter *et al*., 2014). Therefore in a future where climate variability is predicted, it is important to future-proof crop production that is, study crop growth and yield under these predicted conditions. With arable lands predicted to get increasingly saline due to both primary and secondary salinization, salinity is an important stressor of research interest. The effects of salinity stress on crop plants vary, for example in species like *Arthrocnemum macrostachyum* (Moric) C. Koch also known as extreme halophytes, salinity stress has been shown to improve plant growth and photosynthetic parameters (Redondo-Gomez *et al*., 2010). In *Solanum tuberosum* L., salinity stress significantly reduced growth and yield of the species (Tabot *et al*., 2018). Therefore species and varieties are differently adapted to salinity stress. Another line of research in salinity tolerance of crop plants is amendment of soils with nitrogen fertilizers to improve nutrient levels in the soil, the idea being to make the plants healthier

and increase plant levels of nitrates which are essential in the synthesis of many biomolecules which are necessary for growth, yield and stress survival (Ahanger *et al*., 2019; Khan *et al*., 2017).

Among the important vegetable crop plants of Cameroon is *Vernonia hymenolepis* A. Rich., known commonly as 'Bayangi Bitterleaf'. It is used in several dishes, and even as a medicinal plant (Mih and Ndam, 2007). It is produced year-round in Cameroon's Agroecological Zone IV, but its production is more profitable in the off-season under irrigated conditions. In a future of predicted increases in salinity of arable lands, knowledge of how such irrigated production would fare is essential for consolidation of this crop in the future. This research aims at bridging this knowledge gap. We hypothesised that as levels of salinity in the soil increase above the ambient, the plant growth, yield and photosynthetic efficiency would deteriorate significantly, but this deterioration would be ameliorated if nitrate concentrations in the soil are improved.

Materials and methods

Characteristics of the study site

The experimental Station was in SOWEFCU Kumba, South-West Region, Cameroon at latitude 04.628° 58', longitude E 009.444° 98' W and elevation of 237 m. This site is in the humid forest Agro-ecological Zone IV with monomodal rainfall regime. The temperature and relative humidity variation within the screenhouse during the experiment are shown on Fig. 1. The screen-house was open sided with plastic covers estimated to have good light transmission quality and ambient CO_2 levels.

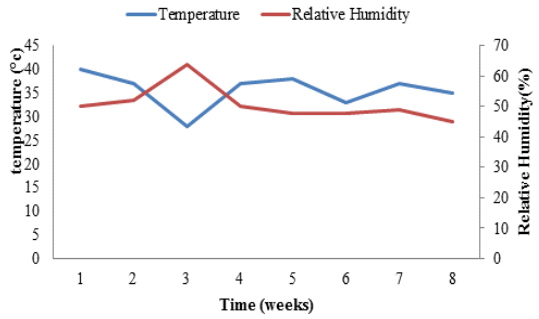

Fig. 1. Variation of temperature and relative humidity in the screen house during the experiment.

Plant material and Experimental design

The species studied was *Vernonia hymenolepis* A.Rich., known commonly as 'Bayangi Bitterleaf'. It is a member of the Asteraceae family, and is valued as a nutritious vegetable in the Central African sub-region. The seeds were obtained from the seed bank of the Department of Agriculture at HTTTC Kumba, saved from the previous season. The viability of the seeds was 85% at sowing. For this experiment, eighty-one seedlings of *Vernonia hymenolepis* were used; these were put in 27 five litre pots. Three plants were sown per pot. Each pot was perforated at the bottom and placed on benches. The experiment was a factorial experiment. There were two factors namely salinity and NPK 20:10:10 fertilizer. There were three levels of salinity (0ppt, 2ppt, 4ppt) and three levels of NPK 20:10:10 fertilizer (0, 4, 8g/pot). This resulted in a 3x3 factorial experiment with 9 treatments. The experiment was replicated three times per treatment, resulting in 27 experimental units (pots). Within each pot, three plants were sown, giving a total of 81 plants. The 9 treatments were assigned to 27 pots randomly, to cancel out differences in microclimate within the screenhouse. Salinity treatments were obtained by diluting seawater with freshwater. NPK 20:10:10 was applied at the three rates during the first week of treatments.

Pre-planting soil analysis

Top soil was collected from the research site and homogenised. The samples were air-dried, then sieved through a 2mm sieve and sent to the Plant and Soil Laboratory of the University of Dschang, where they were analysed using standard APHA methods. The results showed that the soils are sandy clay, with a pH_{KCl} of 5.15, organic matter of 3.83% and carbon:nitrogen ratio of 11. The total exchangeable cations were 5.34 me/100g, with available phosphorus of 18.85 mg/kg with effective cations exchange capacity of 5.45. This showed that the soil was sufficiently fertile and suitable for growth of *V. hymenolepis*.

Sowing

Intact seeds, homogeneous and identical in size and color, and free from wrinkles, were chosen then broadcasted in one plot in the nursery, and watered

daily. The seeds were mixed with sand before broadcasting to ensure uniform spread that is essential for uniform germination and vigor. *Vernonia hymenolepis* seeds were nursed on prepared nursery beds (Fig. 2) and transplanted unto the pots, at the rate of three plants per pot, six weeks after germination. The pots were distributed randomly.

Fig. 2. *Vernonia hymenolepis* plants in the nursery at the time of transplanting.

Treatment application

The control plants received only freshwater. To avoid osmotic shock due to high concentrations, treatments were started on lower concentrations, then the concentration was increased on a daily basis, until each group reached the concentration determined for it. Treatments were administered by irrigating with 500 ml water of the relevant salinity, three times a week (split irrigation).

Agronomic practices

The pots were filled with top soil and well watered before sowing. Weeding was done after transplanting to prevent competition between the plants and weeds. The first weeding was carried out three weeks after transplanting and the second and third weeding were carried six and eight weeks respectively after transplanting. Funguran (Cacaocides 2010 5WP) was applied at 2g per 2litres of water to the experimental pots to prevent infection of fungal diseases on the *Vernonia* plants. This was done every 10 days after germination till time of harvest.

Data collection

Data were collected on height of plants; number of leaves; collar diameter; number of branches; relative leaf area; shoots and roots mass and chlorophyll fluorescence (fv/fm).

Plant height

Plant height was measured with a meter rule graduated incm. This was done by measuring the plant from the base at the ground level to the terminal growth point. The height was recorded for the sampled plants and the mean height per plant determined by dividing the total heights by the number of plants.

Number of leaves and branches

The matured leaves per plant were counted for five plants per replicate and the average number of leaves per plant calculated by dividing the total number of leaves by the number of plants sampled. The number of branches per plant were counted and recorded. The mean number of branches was calculated dividing this total by the number of plants.

Leaf area

Leaf lengths and widths were measured, and the leaf area of the leaf calculated according to the formula:

$RLA = 0.64\ (LL * LW)$.....Eqn 1

Root: Shoot Ratio

The shoots and roots were harvested at the end of the experiment. The fresh masses were measured using an electronic balance, and recorded. Root: Shoot Ratio was calculated as a fraction of the root mass to the shoot mass.

$$\boldsymbol{Root:shoot\ ratio} = \frac{root\ mass\ (g)}{shoot\ mass\ (g)}$$ .....Eqn. 2

Biomass

The roots were separated from shoots and both weighed with a sensitive balance to determine the fresh mass. They were then oven-dried at 60°C for 48 hours, and reweighed to obtain the dry mass. Total plant biomass was computed by adding the root and shoot dry mass.

Harvest index (HI)

The harvest index was calculated according to the equation:

$$HI = \frac{Economic\ yield}{Biological\ yield} = \frac{\text{Shoot fresh mass}}{\text{Total plant dry mass}}$$.....Eqn 3

Water Use Efficiency (WUE)

The water use efficiency which measures the efficiency of conversion of water into biomass was calculated according to Egbe *et al.* (2014):

$$\mathbf{WUE}\left(\frac{\mathbf{g}}{\mathbf{L}}\right) = \frac{\text{total plants biomass}}{\text{total amount of water applied}}$$ .....Eqn. 4

Relative Growth Rate (RGR)

At the start of the experiment, a sample of 10 seedlings were harvested, washed, and oven-dried in an air-flow oven at 60 °C for 48 hours and the mass recorded as the initial mass (w1). At the end of the experiment, the total biomass of each plant was obtained as described in Section 2.11 and recorded as the final mass (w2). The relative growth rate was then calculated as follows:

$$\boldsymbol{RGR}\ (\boldsymbol{g\ g^{-1}week^{-1}}) = \frac{\boldsymbol{LN\ W2 - LN\ W1}}{\boldsymbol{t2 - t1}}$$ (Tabot and Adams, 2012).....Eqn. 5

Where t2 – t1 is the duration of the experiment in weeks.

Chlorophyll fluorescence

This was measured as the ratio of the variable fluorescence (fv) to the maximum fluorescence (fm) using the Hansatech Pocket Plant Efficiency Analyzer (PEA) (Hansatech Instruments Ltd., Norfolk, UK). The plants were dark adapted for 4 minutes, determined a priori by measuring photosynthetic efficiency over 30 seconds intervals and the time for maximum photosynthetic efficiency recorded as the dark adaptation time. After dark adaptation, the chlorophyll florescence was recorded immediately, after illuminating with a single actinic light source at an intensity of 3500µmol $m^{-2}s^{-1}$. All measurements were taken at midday.

Data analysis

Data were analysed for variance in main and interaction effects using the General Linear Model ANOVA procedure, after positive tests for normality and homogeneity of variance. Means were separated through the Dunnett test which compares each mean against the control level (0 ppt for salinity and 0 g fertilizer). Pearson Correlation was done to determine relationship between variables and these were spatially projected using the Factor Analysis procedure, without rotation. These analysis were done at α = 0.05, in the Minitab Version 17 Statistical package (Minitab Inc., USA). Some charts were produced using Microsoft Excel 2013 (Microsoft Inc., USA).

Results

Height

Over 9 weeks, plant heights continued to increase. Main effects were not significant on plant height but the two way interaction of salinity and fertilizer was significant ($p<0.001$). Generally, plants under freshwater treatments were shorter compared to those irrigated with 2 and 4 ppt saline water (Table 1). Within salinity levels, plant heights were statistically different across levels of fertilizer. Plants were significantly taller in the 2 ppt salinity treatment. Within the saline treatments (2 and 4 ppt), increasing fertilizer rates improved plant height (Table 1).

Table 1. Interactive effect of salinity and fertilization on height of *V. hymenolepis* in screen house.

Salinity (ppt)	Fertilizer (g/plant)	Plant height (cm)
0	0	32.38bcd
	4	28.7d
	8	30.43d
2	0	35.88ab
	4	37.47a
	8	36.77a
4	0	31.49cd
	4	31.25cd
	8	35.43abc

Values represent means. Means separated through GLM ANOVA with Dunnett test at α=0.05. Means with the same letter within the column are not statistically different.

Number of leaves and branches

Plants of the control salinity level (0 ppt) had fewer leaves (19 to 21) compared to those at 4 and 8 ppt salinity (26.07 to 29.48 leaves per plant). These differences were statistically significant (<0.05). The number of branches increased in all treatments above the control levels. There were averagely 6.65 branches in plants treated with 4 ppt and 8 g fertilizer compared to zero for the control. Branches in the rest of the treatments ranged from 3.67 to 5.81 but control plants were not branched. These results were statistically significant ($p<0.05$).

Leaf area (LA)

Leaf area of the plants are presented in Table 2. Plants of the control treatments (0 ppt at 0 g NPK fertilization) had high LA similar to those of the other treatments. As fertilizer rates increased within the freshwater treated plants, RLA statistically reduced ($p<0.05$). Relative leaf areas of plants under the 2 ppt salinity treatments were statistically similar across fertilizer rates, while those under the 4 ppt salinity treatments increased as fertilization rates increased (Table 2).

Table 2. Interactive effect of salinity and fertilization on LA of *V. hymenolepis* in screen house.

Salinity (ppt)	Fertilizer (g/plant)	LA (cm^2)
0	0	24.16ab
	4	18.27bc
	8	16.59c
2	0	24.87ab
	4	25.94a
	8	22.40abc
4	0	17.56c
	4	24.71a
	8	27.72abc

Values represent means. Means separated through GLM ANOVA with Dunnett test at α=0.05. Means with the same letter within the column are not statistically different. LA = Leaf area.

Biomass partitioning

Table 3 shows analysis of variance results of the main and interaction effects of salinity and fertilization on biomass partitioning in *V. hymenolepis*. Salinity did not have a significant effect on any of the measured parameters ($p>0.05$ in all cases). On the other hand, fertilizer significantly affected biomass partitions, harvest index, WUE and RGR ($p<0.05$ in all cases). The interaction of fertilizer and salinity did not significantly affect any of the parameters measured (Table 3).

Biomass, RGR, HI and WUE values of plants treated with salinity regimes ranging from 0 to 4 ppt were statistically similar. Table 4 therefore shows that salinity of 2 to 4 ppt had a similar effect on biomass partitions of *V. hymenolepis* as the control (0 ppt). On the other hand, the fertilizer effect varied significantly across salinity levels. The highest values of shoot mass, root mass, biomass, WUE and RGR were recorded in plants grown on saline and non-saline soils amended with 4 g/plant NPK 20:10:10 fertilizer (Table 4).

Table 3. Analysis of variance results on statistical significance of salinity and fertilization effects on growth and yield of *Vernonia hymenolepis* in screenhouse.

Source	Shoot FM/g	Shoot DM/g	Root FM/g	Root DM/g	R:S ratio	HI	Biomass	WUE	RGR
S	0.091	0.829	0.100	0.136	0.603	0.171	0.365	0.365	0.402
F	0.001	0.003	0.003	0.013	0.010	0.005	0.004	0.004	0.004
S*F	0.427	0.591	0.709	0.742	0.992	0.611	0.420	0.420	0.412

Values represent levels of significance. P-Value less than 0.05 indicate statistical variation in the effect of the measured factor on the response variable

Table 4. Growth and yield responses of *Vernonia hymenolepis* to salinity and fertilization with NPK 20:10:10, in screenhouse.

Salinity (ppt)	Shoot FM/g	Shoot DM/g	Root FM/g	Root DM/g	R:S ratio	HI	Biomass (g)	WUE	RGR
0	66.00a	23.00a	36.44a	9.67a	0.43a	2.02a	32.67a	2.72a	0.23a
2	76.44a	24.56a	38.44a	12.22a	0.52a	2.06a	36.78a	3.07a	0.24a
4	60.22a	24.00a	28.44a	10.33a	0.51a	1.77a	34.33a	2.86a	0.23a
Fert. (g/plt)									
0	49.78a	18.89a	41.89a	12.00a	0.68a	1.61a	30.89a	2.57a	0.22a
4	81.44b	29.11b	37.67a	11.89a	0.42b	2.02b	41.00b	3.42b	0.25b
8	71.44b	23.56a	23.78b	8.33b	0.37b	2.22b	31.89a	2.66a	0.22a

Values represent means. Means separated through GLM ANOVA with Dunnett test at α=0.05. Means with the same letter within the column for each main effect are not statistically different. Fert. = fertilizer, FM= fresh mass, DM = dry mass, HI = harvest index, R:S ratio = root:shoot ratio, WUE = water use efficiency, RGR = relative growth rate

Biomass, WUE and RGR values of plants grown in pots treated with the higher levels of NPK fertilizer (8 g/plant) were statistically similar to those of the control (og NPK 20:10:0 fertilizer per plant). However, Root:Shoot ratio of plants that did not receive any fertilizer was significantly higher (0.68) compared to that of plants grown on soils amended with 4, and 8 g NPK 20:10:10 per plant (0.42 and 0.37 respectively) (Table 4).

Interaction effects of salinity and fertilization on growth and yield parameters are presented in Fig. 3. The best HI was recorded in plants grown on soils amended with 8 g NPK 20:10:10 fertilizer across all salinity levels (Fig. 3A). The lowest HI was recorded in plants that did not receive any fertilizer, irrespective of salinity. On the other hand, Root:Shoot ratio patterns were reversed. The best Root:Shoot ratio was recorded in plants that did not receive any fertilizer, and this did not depend on any salinity treatments (Fig. 3B) while plants treated with 8 g NPK 20:10:10 fertilizer had the least root:shoot ratio. With respect or RGR and WUE, plants grown in soils amended with 4g NPK 20:10:10 performed best across salinity levels while plants that did not receive any fertilizer performed least (Fig. 3C and 3D).

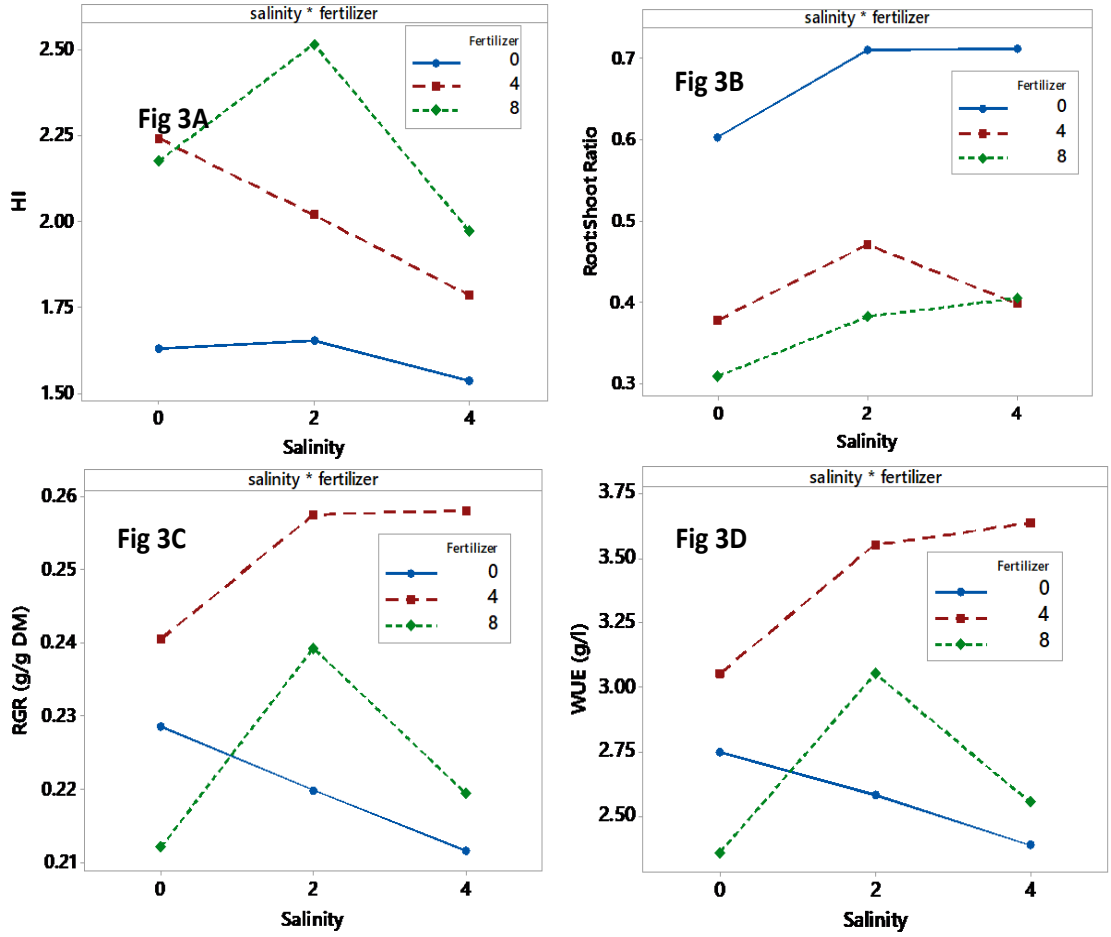

Fig. 3. Effect of interaction of salinity and fertilization with NPK 20:10:10 on Harvest Index (Fig. 3A), Root:shoot ratio (Fig. 3B), RGR (Fig. 3C) and water Use Efficiency (Fig 3D) of *Vernonia hymenolepis* in Screenhouse.

Chlorophyll fluorescence (fv/fm)

The efficiency of photosystem II photochemistry measured as the ratio of the variable fluorescence (fv) to the maximum fluorescence (fm) did not vary significantly across main and interaction effects ($p>0.05$) in all cases. Table 5 shows the interaction effects of salinity and NPK20:10:10 fertilization on photosynthetic efficiency. All values recorded were below 0.8, indicating that the plants suffered some degree of stress, including the control plants.

Table 5. Chlorophyll fluorescence responses of *Vernonia hymenolepis* to salinity and fertilization with NPK 20:10:10, in screenhouse.

Salinity	Fertilizer	fv/fm
0	0	0.722a
0	4	0.720a
0	8	0.727a
2	0	0.722a
2	4	0.722a
2	8	0.727a
4	0	0.716a
4	4	0.721a
4	8	0.721a

Values represent means. Means separated through GLM ANOVA with Dunnett test at α=0.05. Means with the same letter within the column for each main effect are not statistically different. Fv/fm = chlorophyll fuorescence

Factor analysis and correlation

Correlation analyses (data not shown) show that there were no correlations between salinity and the measured parameters (p>0.05). On the other hand, there were significant correlations between fertilizer rates and shoot fresh mass (p = 0.021, r = 0.442); harvest index (p = 0.021, r =0.602), root fresh mass (p = 0.001, r = -0.603) and root: shoot ratio (p = 0.002, r = -0.580). Water use efficiency depended strongly on root dry mass (p = 0.010, r = 0.487) while RGR also had a strong positive correlation with root dry mass (p = 0.010, r = 0.490). There were no correlations with chlorophyll fluorescence. Factor analysis of the correlation matrix is presented in Fig. 4 and shows that there is a strong association between shoot growth parameters and NPK 20:10:10 fertilizer on the one hand, which are negatively associated with root growth parameters such as root fresh mass, root dry mass and R:S ratio.

Factor analysis also shows that for this species, the salinity effect was not significantly associated with any of the measured parameters. The loading plot (Fig. 4) shows that 77.1% of the observed variations in the growth and yield parameters measured can be explained mainly by fertilizer influences (44.3% in the first factor and 32.8% in the second factor) with salinity playing a minor role. This also means that other factors not studied also account for 22.9% of the observed variations in the response variables (Fig. 4).

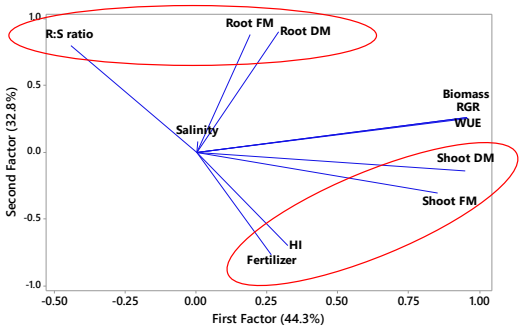

Fig. 4. Loading plot of the relationship between fertilizer and salinity effects with growth and yield parameters of *V. hymenolepis* in screenhouse.

Discussion

There is slight stimulation of growth parameters of *V. hymenolepis* such as height and number of branching as salinity increased from 0 to 2ppt; this is probably because slight increases in salinity stimulate the plant to rally adaptive mechanisms of salt stress tolerance that eventually over-compensate for the effect of the stress. Within the saline treatments, increasing fertilization with NPK 20:10:10 further increased these growth parameters, probably because fertilization with NPK 20:10:10 provides much needed nitrates that compensate for the limitation through fixing soil nutrients due to the saline nature of the soils. These excess nitrates go into building biomolecules for salinity stress tolerance (such as proline and glycinebetaine which are compatible osmolytes, as well as enzymes) and hence growth and photosynthesis are enhanced, as reported for mustard (Umar *et al.*, 2015; Garg *et al.*, 2006).

Biomass partitioning in *V. hymenolepis* did not respond to salinity treatments but increased with fertilization with 4g NPK 20:10:10 per pot, which was a threshold; further increase of fertilization to 8g/pot suppressed biomass partitions across treatments. How biomass is allocated to different parts of the plant gives further insights to the survival and performance strategies of the plant under salinity stress. In the current research the salinity effect on biomass partitioning seems to have been cancelled by the coping mechanisms of the plant. It was expected that root growth would reduce for example, due to reduction of root cell growth, as has been reported for

tomato (Zhang *et al*., 2016) and potato (Tabot *et al*., 2018) but this was not observed. Rather, while similar across salinity regimes, root:shoot ratio decreased significantly as fertilization was increased above the control. The higher root:shoot ratio in the unfertilized plants could be a strategy for better foraging for nutrients, which become fixed in soil saline conditions, consistent with findings by Acosta-Motos *et al*. (2017).

With respect to fertilizer enhancement, the 4g/pot NPK 20:10:10 treatments seem to be a threshold for growth performance under conditions in the screenhouse, as it resulted in significantly higher WUE and RGR compared to the other treatments, irrespective of salinity. Nitrogen in fertilizer is an essential nutrient for plant health. Healthier plants grow better and hence produce more biomass per unit of irrigation water applied.

Nitrogen is essential for chlorophyll formation, amino acids, proteins and enzymes including RUBISCO that is central to the process of photosynthesis (Umar *et al*., 2015; del Amor and Cuadra-Crespo, 2011; Shaddad *et al*., 1988). Interaction effects showed that the best HI was recorded in plants that received the highest level of fertilizer irrespective of salinity, implying stimulation of vegetative growth relative to biomass accumulation (Engelbrecht *et al*., 2013). This was the opposite pattern recorded for root:shoot ratio, which was best under non-fertilized conditions.

Although fv/fm values indicated that the plants were all stressed and displayed inefficient photosynthesis, a threshold for biomass partitions, RGR and WUE was found at at 4g/pot fertilization irrespective of salinity. Factor analysis show a positive correlation of fertilizer with [shoot biomass and harvest index parameters, a negative correlation with root biomass and root:shoot ratio, and cancelling the potential salinity effects on the plants. This represents an adaptation strategy driven by nitrogen enhancement, where vegetative growth is promoted aboveground while root production below ground is suppressed, because sufficient nitrogen availability in fertilized plants eliminates the need for re-allocation of photosynthate and ATP for root architecture (Leghari *et al*., 2016).

Conclusion

In conclusion, growth and biomass partitioning in *V. hymenolepis* is stimulated under mild salinity levels, ameliorated with NPK fertilization. Therefore in soils suffering salinization up to 4ppt, we can still expect enhanced production of *V. hymenolepis* at a sustainable rate.

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Conflict of interest

The authors declare that there is no conflict of interest.

Compliance with ethical standards

This research complied with the standards for research in applied sciences in Cameroon. It did not require an ethics clearance certificate, which is only required for research involving human and animal subjects.

Data availability

All relevant analyses have been done and presented in the manuscript. However, all raw data is available from the corresponding author upon request.

References

Acosta-Motos JR, Ortuño MF, Bernal-vicente A, Diaz-vivancos P, Sanchez-blanco MJ, Hernandez JA. 2017. Plant Responses to Salt Stress : Adaptive Mechanisms. Agronomy **7(18),** 1-38.

Aggarwal PK. 2009. Determinants of Crop Growth and Yield in a Changing Climate. In: Wani PS, Rockstrom J, Oweis T, Eds. Rainfed Agriculture: Unlocking the potential. Oxfordshire, UK. CABI p. 73-80.

Ahanger MA, Qin C, Begum N, Maodong Q, Dong XX, El-Esawi M, El-Sheikh MA, Alatar AA, Zhang L. 2019. Nitrogen availability prevents oxidative effects of salinity on wheat growth and photosynthesis by up-regulating the antioxidants and osmolytes metabolism and secondary metabolite accumulation. BMC Plant Biology **19(1),** 1-12.

del Amor FM, Cuadra-Crespo P. 2011. Alleviation of salinity stress in broccoli using foliar urea or methyl-jasmonate: Analysis of growth gas exchange and isotope composition. Plant Growth Regulation **631,** 55-62.

Egbe EA, Yong FE, Ayamoh EE. 2014. Evaluation of Seedlings of Three Woody Species under Four Soil Moisture Capacities. British Journal of Applied Science and Technology **424,** 3455-3472.

Aslam M, Ahmad K, Akhtar MA, Maqbool MA. 2017. Salinity Stress in Crop Plants: Effects of stress Tolerance Mechanisms and Breeding Strategies for Improvement. Journal of Agriculture and Basic Sciences **2,** 70-85.

Asseng S, Ewert F, Martre P, Rötter RP, Lobell DB, Cammarano D, Kimball BA, Ottman MJ, Wall GW, White JW, Reynolds MP, Alderman PD, Prasad PVV, Aggarwal PK, Anothai J, Basso B, Biernath C, Challinor AJ, De Sanctis G, Zhu Y. 2015. Rising temperatures reduce global wheat production. Nature Climate Change **52,** 143-147.

Athar HR, Ashraf M. 2009. Strategies for Crop Improvement Against Salinity and Drought Stress: An Overview. In: Ashraf M, Ed. Salinity and Water Stress. Singapore: Springer p 1-16.

Cuevas J, Daliakopoulos IN, Del Moral F, Hueso JJ, Tsanis IK. 2019. A review of soil-improving cropping systems for soil salinization. Agronomy **96,** 1-22.

El-RheemKh AM, Zaki SS. 2017. Effect of Soil Salinity on Growth Yield and Nutrient Balance of Peanut Plants. Journal of Degraded and Mining Lands Management **44,** 945-954.

Engelbrecht GM, du Preez CC, Spies JJ. 2013. Response of Lachenalia growing in soil to nitrogen fertilization during the nursery phase. South African Journal of Plant and Soil **24(4),** 220-227.

Garg BK, Burman U, Kathju S. 2006. Alleviation of salinity stress effects on photosynthesis nitrogen metabolism and yield of indian mustard by nitrogen fertilization. Indian Journal of Plant Physiology **11(2),** 145-151.

Khan A, Kean D, Tan Y, Muhammad AZ, Luo H, Shahbaz TA, Ajab M, Fahad S. 2017. Nitrogen fertility and abiotic stresses management in cotton crop: a review. Environmental Science and Pollution Research **24,** 14551-14566.

Leghari SJ, Wahocho NA, Laghari GM, Hafeez LA, Mustafa BG, Hussain TK, Bhutto TA, Wahocho SA, Lashari AA. 2016. Role of nitrogen for plant growth and development: a review. Advances in Environmental Biology **109,** 209-219.

Maathuis FJM, Ahmad I, Patishtan J. 2014. Regulation of Na+ fluxes in plants. Frontiers in Plant Science **5,** 1-9.

Majeed A, Siyyar S. 2020. Salinity Stress Management in Field Crops: An Overview of the Agronomic Approaches. In M Hasanuzzaman Ed. Plant Ecophysiology and Adaptation under Climate Change: Mechanisms and Perspectives II. Singapore, Springer p. 1-16.

Mih A, Ndam L. 2007. Seed production of *Vernonia hymenolepis* A. Rich Asteraceae under different foliage harvest regimes. Journal of the Cameroon Academy of Sciences **72,** 149-166.

Mo XG, Hu S, Lin ZH, Liu SX, Xia J. 2017. Impacts of climate change on agricultural water resources and adaptation on the North China Plain. Advances in Climate Change Research **82,** 93-98.

Porter J, Xie L, Challinor A, Cochraine K, Howden S, Iqbal M, Lobell D, Travasso M. 2014. Food Security and Food Production Systems. In Aggarwal P, Ed. Climate Change 2014: Impacts Adaptation and Vulnerability Part A: Global and Sectoral Aspects Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge University Press p. 485-533.

Postel SL. 1998. Water for Food Production: Will There Be Enough in 2025? BioScience **488,** 629-637.

Redondo-Gomez S, Mateos-Naranjo E, Figueroa ME, Davy AJ. 2010. Salt stimulation of growth and photosynthesis in an extreme halophyte *Arthrocnemum macrostachyum*. Plant Biology **121,** 79-87.

Rossato L, Alvalá RC, do Marengo JA, Zeri M, Cunha APM, Pires LBM, Barbosa HA. 2017. Impact of soil moisture on crop yields over Brazilian semiarid. Frontiers in Environmental Science ***5*,** 1-16.

Shaddad MA, Ahmed AM, Fayez KA. 1988. Alleviation of the adverse effects of salinity by nitrogen fertilization. Biologia Plantarum **305,** 343-350.

Shrivastava P, Kumar R. 2015. Soil salinity: A serious environmental issue and plant growth promoting bacteria as one of the tools for its alleviation. Saudi Journal of Biological Sciences **22(2),** 123-131.

Siebert S, Döll P. 2010. Quantifying blue and green virtual water contents in global crop production as well as potential production losses without irrigation. Journal of Hydrology **384(3-4),** 198-217.

Tabot PT, Adams JB. 2012. Morphological and physiological responses of *Triglochin buchenaui* Köcke Mering & Kadereit to various combinations of water and salinity: Implications for resilience to climate change. Wetlands Ecology and Management **20,** 373-388.

Tabot PT, Adams JB. 2014. Salt secretion proline accumulation and increased branching confer tolerance to drought and salinity in the endemic halophyte Limonium linifolium. South African Journal of Botany **94,** 64-73.

Tabot PT, Mbega SN, Tchapga NFJ. 2018. Ecophysiological responses of potato *Solanum tuberosum* to salinity and nitrogen fertilization in Screenhouse Cameroon. Tropical and Subtropical Agroecosystems **21,** 547-556.

Umar S, Iqbal N, Khan NA. 2015. Nitrogen availability regulates proline and ethylene production and alleviates salinity stress in mustard. Journal of Plant Physiology **178,** 84-91.

Volkov V, Beilby MJ. 2017. Editorial: Salinity tolerance in plants: Mechanisms and regulation of ion transport. Frontiers in Plant Science **8,** 1-4.

Wu H, Shabala L, Liu X, Azzarello E, Zhou M, Pandolfi C, Chen ZH, Bose J, Mancuso S, Shabala S. 2015. Linking salinity stress tolerance with tissue-specific Na+ sequestration in wheat roots. Frontiers in Plant Science **6,** 1-13.

Xia J, Duan QY, Luo Y, Xie ZH, Liu ZY, Mo XG. 2017. Climate change and water resources: Case study of Eastern Monsoon Region of China. Advances in Climate Change Research **82,** 63-67.

Zhang P, Senge M, Dai Y. 2016. Effects of salinity stress on growth yield fruit quality and water use efficiency of tomato under hydroponics system. Reviews in Agricultural Science **4,** 46-55.