A study of the impact of salinity on growth and development of important tomato and banana cultivars of the Jordan Valley with an assessment of the efficacy of biostimulants as ameliorants for increased tolerance to salinity

by

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DECLARATION

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Summary

Soil salinity is a major challenge to farmers in the Middle East in general, but particularly so in Jordan, where salinization of irrigation water sources puts additional pressure on production systems, already experiencing significant climatic and soil-related stresses. To meet these challenges farmers are forced to implement new cultural practises, while consistently having to screen for more tolerant cultivars, in addition to considering the application of ameliorants, in order to deliver high quality fresh produce in a profitable and sustainable manner.

This study, consisting of four experiments, focused on tomato and banana, both major crops grown in the Jordan valley. The study aimed in the first two trials to identify the most tolerant cultivars of these two crops, as determined through a range of growth parameters. The next part of the study aimed to determine the efficiency of a range of soil ameliorants and biostimulants in the various cultivars per crop to increase their resistance to salinity as demonstrated through vegetative and reproductive growth parameters.

For the first objective an experiment was conducted on five determinate tomato varieties, namely 'Majd', 'Alam', 'Asalah', 'Ayah' and 'Bahjah' over a summer and a winter planting season, through the addition of NaCl at five increasing concentrations to the daily fertigation solution, where after vegetative traits were observed over a six-week period. Results showed cultivars differed in their resistance to salinity and ranked in general from tolerant to susceptible: 'Ayah'; 'Alam'; 'Majd'; 'Asalah' and 'Bahjah'.

In the second objective the same procedures as described above was followed, but where two banana cultivars, 'Grand Nain' and 'Paz' were assessed for salinity tolerance. Similar to the tomato experiment, plants were subjected to five increasing NaCl concentrations that was added to the daily fertigation solution, for both a summer and winter planting phase of six weeks each. Again, the increase in salinity concentration significantly decreased all plant growth parameters. In addition, results showed a significance decrease in growth rate and associated morphological traits with increasing salinity concentration, with 'Grand Nain' being the more vigorous cultivar compared to the 'Paz' cultivar, although not significant so for all parameters.

In the third objective the efficacy of compost, glycine betaine, bacteria, kelp, sulphuric acid and a mix of compost and glycine betaine treatments was evaluated for their ability to ameliorate the effect of salinity on the two tomato cultivars, 'Ayah' and 'Bahjah', by assessing both morphological and production traits such as plant height, leaf number, leaf width, fruit number and weight, along with fresh and dry weights of the shoot and root. The compost treatment produced the best amelioration result, and was followed by the compost and glycine betaine combination treatment. Glycine betaine mostly promoted vegetative growth and above ground production, whereas the Kelp treatment benefited root growth and weight. Sulphuric acid as a treatment was inconsistent and at times even impacted negatively on growth compared to the control. ‘Ayah’ performed significantly better in all parameters compared to ‘Bahjah’.

The fourth experiment was conducted on the two banana cultivars ‘Grand Nain’ and ‘Paz’, over a two-month period, following a similar experimental design than used for the tomato trial, with a few small amendments, as the bacteria treatment omitted, while the glycine betaine was applied at two application intervals. Results indicated that the compost and glycine betaine treatments were more successful in ameliorating salinity than the kelp or sulphuric acid treatments. ‘Paz’ consistently showed greater saline tolerance than ‘Grand Nain’.

The use of biostimulants, whether applied to the soil or as a foliar application, used either as a single product or in combination, showed considerable potential to ameliorate salinity, both in tomato and banana. More studies is required to determine the profitability of these approaches before a commercial recommendation can be made.

Opsomming

Grondversouting is ‘n groot uitdaging vir boere in die Midde-Ooste in die algemeen, maar in die besonder so vir Jordanië waar versouting van besproeiingsbronne addisionele druk plaas op produksiesisteme wat reeds klimaats- en ander grondverwante stres ervaar. Om hierdie uitdagings te oorkom word boere geforseer om voortdurend nuwe verbouingspraktyke te implementeer, terwyl daar gesoek moet word na meer weerstandbiedende kultivars, asook die oorweging van moontlike toedienings van ameliorante om die produksie van hoë kwaliteit vars produkte in ‘n winsgewende en volhoubare manier te verseker.

Hierdie studie bestaan uit vier eksperimente en fokus op tamatie en piesang, beide belangrike gewasse wat in die Jordanië vallei verbou word. Die eerste deel van die studie het ten doel gehad om die mees weerstandbiedende kultivars te identifiseer van die twee gewasse wat bestudeer is, gebaseer op ŉ reeks van waargeneemde groei parameters. In die volgende deel van die studie is gepoog om die effektiwiteit van ŉ reeks grond ameliorante en biostimulante te evalueer om sout toleransie in die verskeie kultivars per gewas te induseer soos gedemonstreer word deur vegetatiewe en reproduktiewe parameters.

Vir die eerste doelwit is ŉ eksperiment uitgevoer op vyf bepaalde tamatie variëteite, naamlik ‘Majd’, ‘Alam’, ‘Asalah’, ‘Ayah’, en ‘Bahjah’, oor beide ŉ somer en winter aanplanting-seisoen. NaCl is teen vyf toenemende konsentrasies by die daaglikse bemestingsoplossing gevoeg, waarna vegetatiewe kenmerke oor ŉ ses-week periode gevolg is. Daar is waargeneem dat die toename in soutkonsentrasie ŉ betekenisvolle afname in alle plantgroei parameters veroorsaak het. Variëteite het verskil in hul toleransie teen versouting, en het gewissel van tolerant tot vatbaar in die volgorde: ‘Ayah’; ‘Alam’; ‘Majd’; ‘Asalah’; en ‘Bahjah’.

In ‘n tweede doelwit is dieselfde prosedures gevolg soos bostaande beskryf is maar vir die twee piesangs kultivars, ‘Grand Nain’ en ‘Paz’. Soos met die tamatie eksperiment was plante onderworpe aan vyf toenemende konsentrasie van NaCl wat by die daaglike bemestingsbesproeiing gevoeg is, vir beide ŉ somer en winter aanplantingsfase van ses weke elk. Resultate dui ŉ betekenisvolle afname in groeitempo en geassosieerde vegetatiewe eienskappe aan met toenemende sout konsentrasie, met ‘Grand Nain’ wat meer groeikragtig en soutbestand vertoon het in vergelyking met ‘Paz’, alhoewel dit nie betekenisvol verskillend was vir alle parameters nie.

In die derde doelwit is die effektiwiteit van kompos, glisienbetaine, bakterieë, kelp, swawelsuur en ŉ mengsel van kompos en glisienbetaine geëvalueer vir hulle vermoë om die effek van versouting te amelioreer in die twee tamatie kultivars 'Ayah' en 'Bahjah', deur beide morfologiese en produksie eienskappe soos plant hoogte, blaar getal, blaarwydte, aantal vrugte en vrug gewig, asook die vars en droë gewigte van die loot en wortels te assesseer. Die kompos behandeling het die beste ameliorasie resultate behaal, en was gevolg deur die kompos en glisienbetaine kombinasie behandeling. Glisienbetaine het meestal vegetatiewe groei en bogrondse produksie bevorder, teenoor die kelp behandeling wat wortelgroei- en gewig bevorder het. Swawelsuur as ŉ behandeling was inkonsekwent en het soms selfs negatief op groei ingewerk, in vergelyking met die kontrole. 'Ayah' het beter gevaar in alle parameters in vergelyking met 'Bahjah'.

Die vierde eksperiment was uitgevoer op die twee piesang kultivars, 'Grand Nain' en 'Paz', oor ŉ twee maande periode, deur ŉ soortgelyke eksperimentele ontwerp te volg as wat gebruik was vir die tamatie eksperiment, maar met enkele aanpassings, soos dat die bakterieë behandeling uitgelaat is, terwyl die glisienbetaine met twee toedieningsintervalle gedoen is. Resultate dui aan dat die kompos en glisienbetaine behandelings meer suksesvol was om versouting te amelioreer as die kelp of swawelsuurbehandelings. 'Paz' was konstant meer soutbestand as 'Grand Nain'.

Die gebruik van biostimulante, ongeag of dit ŉ grond of blaartoediening is, en of dit as ŉ enkelproduk of in kombinasie gebruik word, toon aansienlike potensiaal om versouting teen te werk, beide in tamatie en piesang. Verdere studies word benodig om die winsgewendheid van hierdie behandelings te bepaal voordat ŉ kommersiële aanbeveling gemaak kan word.

NOTE

This thesis is a compilation of chapters, starting with a literature review, followed by four research papers.

Each paper is prepared as a scientific paper for submission to the *Journal of the American Society for Horticultural Science*.

Repetition or duplication between papers might therefore be necessary. The required spelling is English (United States).

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General Introduction

Salinity has become one of the major threats for the agricultural industry, being a barrier to sustainable food production and food security on a global scale. Salinity can be defined as the accumulation of water-soluble salts in the upper layers of soils to a level where both crop production and environmental health are negatively affected (Rengasamy, 2006). Based on FAO statistics, there are approximately 4 million square kilometres that are considered affected to such a degree that it can be classified as saline soils (FAO Statistics, 2006).

One of the main reasons for soil salinity is saline irrigation water and poor land management practices (Sanon et al., 2015). While many saline soils worldwide can be ascribed to natural causes, poor soil and water management regimes in irrigated areas (Neto et al., 2004) most often lead to salt accumulation over many years within top soils of arid and semi-arid regions (Munns and Tester, 2008). Such soils are considered to be saline when the electric conductivity (EC) of the soil solution reaches 4 dS m^{-1} which is associated with an osmotic pressure of about 0.2 MPa, known to eventually result in significant reduction in yields of most crops (Munns and Tester, 2008).

Salinity effects within all plants presents an major problem, however the salinity effect can vary depending on various environmental effects, but also between plant species which may differ distinctly in their sensitivity towards salinity (Tang et al., 2015). In general, the two main effects resulting from salinity are induced osmotic stress and ionic toxicity. These conditions are associated with excessive Cl^{-} and Na^{+} uptake, which leads to Ca^{2+} and K^{+} deficiencies and/or to other nutrient imbalances (Marschner, 1995). As a result, salinity directly induce a range of physiological, morphological and biochemical changes in the plant (Ashraf and Fooland, 2007) which unavoidable impacts on the production potential of most of the crops (Al-Karaki, 2000).

Two of the major crops in Jordan, a country where most of the farmers have little option but to plant in saline soils and to use saline water for irrigation (Abu-Khadejeh et al., 2012) are banana and tomato. Even though these two crops have different sensitivities towards salinity where banana prefers an EC not exceeding that of 0.15 dS.m^{-1} (Newley and Akehurst, 2008), and tomato require an EC not exceeding that of 3 to 4.5 dS.m^{-1} (De Kreij et al., 1997), both crops are affected negatively by salinity conditions to the extent that production can be severely reduced.

The use of a wide range of soil ameliorants with many methods of application has been a consideration as an amendment to cultivation practices for farmers on saline soils around the word, also including Jordan. However, results have been inconsistent, with some practises being successful, while many others require more research before efficacy can be proved under commercial conditions.

Compost application to the soil has been one of the most common soil ameliorants used by farmers over a long period. Mahdy (2011) who studied the effect of compost on alfalfa *Medicago sativa L.*, reported that a mixed animal waste and plant residues compost reduced the EC and the sodium absorption ratio of saturation soil extracts, while combining compost with chemical fertilizers was effective to reduce the soil pH, soil salinity and soil sodicity. Similarly, result by Oo et al. (2011) on maize showed that compost and vermicompost amendments extracted from cassava industrial waste compost decreased EC, whilst improving cation exchange capacity of the soil, in addition to improvement of soil organic carbon, total nitrogen and extractable phosphorus. Finally, a study by Tartoura et al. (2014) on tomato reported that while salinity resulted in a significant decrease in growth-related parameters, such as shoot- and root-fresh weight (FW), fruit FW, and fruit yield, the use of compost was able to alleviate the salinity and resulted in improved yield-related parameter performance.

Glycine betaine, another widely used ameliorant used by farmers, and has shown promising results under saline conditions. The mode of action of glycine betaine in the plants that are exposed to saline conditions is mainly to maintain osmotic regulation within the cells (Gadallah, 1999). In a study on two varieties of canola, Athar et al. (2009) reported that exogenously applied glycine betaine and proline was equally able to alleviate the effect of salinity on seed germination, in both varieties. Sobahan et al. (2012) reported on the efficacy of glycine betaine to ameliorate the effect of salinity on two rice varieties: ‘Pokkali’ that is considered tolerant to salinity and ‘Nipponbare’ that is known as a salinity sensitive variety. Results showed that the glycine betaine suppressed the salinity effect in the ‘Nipponbare’ variety and improved the K:N ratio in the leaf tissue, while this ratio remained unaffected in the ‘Pokkali’ variety.

Another ameliorant that has received significant attention for soil improvement under saline conditions has been Kelp (seaweed) extracts. A study on wheat in Egypt reported that pre-soaking of wheat seeds in a solution of seaweed extracts extracted from *Ulva lactuca* prior to being sowed on saline soil, have demonstrated a highly significant enhancement in the percentage of seed germination and other growth related parameters (Ibrahim et al., 2014). In an earlier study, but also from Egypt, where wheat was grown in saline soil , Salem and Abdel-Rasoul (2016) reported that a salinity treatment of 6000 ppm NaCl, led to a significance decrease in all growth parameters and morphological traits. When a combination treatment of three products consisting of 2000 ppm seaweed extracts, 2000 ppm potassium nitrate and 200 ppm potassium silicate were applied to these saline soils in pots, it resulted in the alleviation of all stress symptoms and was effective to improve in all growth morphological parameters in the wheat plants .

Sulphuric acid was one of the first ameliorants used in farming on saline soils and operates by lowering the soil pH (Muhammad, 1990). This mode of action has been demonstrated in a study by Khorsandi (2008) on sorghum crop grown in calcareous soil, where the application of sulphuric acid lowered the soil pH, which increased nutrients availability and also eventually the yield.

The current study investigate the effect of salinity on two tomato and two banana cultivars grown in the saline soil of Jordan valley, where cultivar differences are considered as well as the impact of different amelioration products and their effect on morphological and reproductive traits of these two crops. The first objective focused on providing an overview on the extent of salinity as a worldwide problem, and for the Middle East region in general, but more particularly so for Jordan, placing emphasis on tomato and banana as important crops for this region. The applicable of various ameliorants to counteract the negative effects of salinity is also reviewed. In the second and third objective the salinity effect is studied on five tomato and two banana cultivars respectively, as grown in the Jordan valley, to establish whether differences in tolerance to salinity tolerance in present, by studying morphological growth traits.

A fourth objective is to evaluate five biostimulants for its effect on two tomato cultivars. In a fifth objective four biostimulants were assessed for its efficacy to ameliorate the impact of salinity on two banana cultivars grown in the Jordan valley by reporting on various the morphological traits for the banana and tomato study, also including reproductive traits for the tomato experiment.

This study thus aims to provide a better understanding of the effect of salinity on tomato and banana cultivars grown in saline soils of the Jordan valley and possible techniques and products that could be included in management strategies aimed at providing amelioration, and to improve yield and fruit quality.

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Paper 1: Fertilization management and the use of ameliorants and biostimulants on crops grown under saline conditions: a review

1. Introduction

Salinity is currently one of the most important challenges facing commercial agriculture in many areas globally. Salinity can be classified into two main categories, namely that of soil salinity or salinity associated with irrigation. The first record in history of salinity as a major problem detrimental to agriculture was recorded in ancient Mesopotamia (now known as southern Iraq), as early as 2400-1700 B.C. (Jacobson and Adams, 1958).

Today the main cause of salinity associated with irrigated, semi-arid and arid areas around the world is the shortage of water resources, either as rainfall or as ground water, causing insufficient leaching of salts from the root zone, thus resulting in a reduction of crop productivity (Francois and Mass, 1994). Of great concern is the prediction that a warmer climate in future is likely to lead to greater variations in the hydrological circle, amongst other where rising sea levels are expected to most certainly contribute to a significant increase in the number of salinity-affected areas around the world (Tsanis et al., 2015).

Salinity, either in the soil or with irrigation water has various negative effects on crops, ranging from detrimental physiological effects to nutrients uptake, inhibition and competition. These negative influences adversely affect the vegetative growth and development of the plant and finally result in a decrease in production as well as a reduction in the quality of the fresh produce.

In this review, we aim to provide an overview on salinity as a physiological stress on crop plants; discuss the various types of salinity; describe how salinity affects the plant, and highlight some possible practices to overcome this severe problem, with special focus on tomato and banana as two major crops of the Jordan Valley. Finally, research evaluating plant resistance to salinity stress and various possible approaches for adjustments of fertigation regimes of crops cultivated under such saline conditions will be discussed.

2. Defining Salinity

2.1 Water salinity

An accurate definition to describe water salinity is that mentioned in the World Ocean Atlas (2005) where water salinity is defined as “saltiness due to the dissolved salt content in a body of water". Salts in this context refer to either sodium chloride (NaCl), magnesium carbonates ($MgCO_3$), calcium sulphates ($CaSO_4$) or bicarbonates $Ca(HCO_3)_2$ (Henry, 2012).

The best method to quantify water salinity is by means of electrical conductivity (EC_w). A high EC_w implicate less water being available to the plant, as plants only transpires pure water, while available water to the plant in the soil decrease as the EC increase (Bauder et al., 2011). Bauder et al. (2011) explained this concept by stating that irrigation water with an EC_w of 1.15 dS m^{-1} will contain about 2000 pounds (910 kg) salts for every acre foot (1233.48 $meter^3$) of water. As the yield of any crop is directly related to the amount of pure water transpired through the foliage, irrigation water with a high EC_w will certainly reduce production and minimize the yield potential.

Ayers (1977) presented results showing that some crops, like potato, will lose up to 50% of its production potential as the EC_w approaches 3.9 $dS.m^{-1}$ (Table 1). Yet, irrigation water sources with a natural EC_w of more than 3.9 $dS.m^{-1}$ are very commonly reported in water analysis reports of the Gulf States Countries (GCC), as well as in Iraq (personal communication with farmers). Such an EC_w guideline is very useful as it can provide farmers with a quick reference on suitable crops to grow in areas with varying degrees of salinity

Table 1. Potential yield reduction for selected crops when irrigated with saline water (adapted from Ayers, 1977).

	% Yield reduction			
Crop	0%	10%	25%	50%
	EC_w [Y]			
Barley	5.3	6.7	8.7	12.0
Wheat	4.0	4.9	6.4	8.7
Sugar Beet [Z]	4.7	5.8	7.5	10.0
Alfalfa	1.3	2.2	3.6	5.9
Potato	1.1	1.7	2.5	3.9
Corn (grain)	1.1	1.7	2.5	3.9
Corn (silage)	1.2	2.1	3.5	5.7
Onion	0.8	1.2	1.8	2.9
Dry Beans	0.7	1.0	1.5	2.4

[Y] EC_w = electrical conductivity of the irrigation water in $dS.m^{-1}$ at 25 °C

[Z] Sensitive during germination. EC_w should not exceed 3 $dS.m^{-1}$ for garden beets and sugar beets

2.2 Soil salinity

Soil salinity refers to the salt content in the soil, whereas the process of increasing soil salt content is known as salinization. Salinization can be caused by natural processes such as mineral weathering, or develop due to the gradual withdrawal of an ocean, but can also be linked to artificial processes such as long-term irrigation regimes. According to Rengasamy (2006), soil is considered saline if the electrical conductivity of its saturation extract (EC_e) is above 4 dS m^{-1} at 25°C (Richards, 1954).

Flynn and Ulery (2011) define soil salinity as a condition where a soil comprise of sufficient amounts of soluble salts to impair plant productivity. It is however also stated that a soil exhibiting the characteristic white crust may not be necessarily be affected by high sodium, but can still be considered saline as the term "salts" is not limited to table salts (sodium chloride), but also include mineral elements such as calcium, magnesium, and potassium, bicarbonate, carbonate, chloride, sulphate and nitrate. Common components of saline soil are cations like Na^+, Ca^{2+} and Mg^{2+}, along with anions such as Cl^-, SO_4^{2-} and HCO_3^-, but with the ionic crystalline compounds Na^+ and Cl^- still considered the most important cation and anion respectively (Cardon et al., 2007; personal communication; Table 2).

Many of these above-mentioned salts at an appropriate concentration are considered essential plant mineral nutrients, but are toxic at supra-optimal concentrations. High levels of Na^+ results in the deterioration of the physical structure of the soil (Dudley, 1994), while both Na^+ and Cl^- are considered toxic to plants (Hasegawa et al., 2000). From an agricultural point of view, saline soils that contain sufficient neutral soluble salts in the root zone as is required to adversely affect the growth of most crops.

Table 2. Mineral element components of saline soil salts (Adapted from Cardon et al., 2006).

Salt	Cation (+)	Anion (-)	Common name
$NaCl$	Sodium	Chloride	Halite (table salt)
Na_2SO_4	Sodium	Sulphate	Glauber's salt
$MgSO_4$	Magnesium	Sulphate	Epsom salt
$NaHCO_3$ (soda)	Sodium	Carbonate	Baking soda
Na_2CO_3	Sodium	Bicarbonate	Sal soda
$CaSO_4$	Calcium	Sulphate	Gypsum
$CaCO_3$	Calcium	Carbonate	Calcite (lime)

3. Soil Salinity: International importance

Saline soils occur all over the world at varying levels and at different sites. Using the FAO/UNESCO soil map of the world (1970-1980), it was estimated that globally the total area of saline soils is 297 million ha, with sodic soils at 434 million ha (FAO-UNESCO, 1971). Table 3 provides a summary of the extent of salinity worldwide as estimated by the late 1980's. Salinity has been categorized into two types namely, saline soils and sodic soils, where saline soils are those with high amount of different kinds of soluble salts whereas sodic soils specifically refer to those soils containing high amount of sodium (Richards, 1954).

Table 3. Global distribution of saline and sodic soils in million hectares (adapted from Szabolcs, 1989).

	Area (million hectares)		
Continent	Saline	Sodic	Total
North America	6.2	9.6	15.8
Central America	2.0	***[z]	2.0
South America	69.4	59.6	129.0
Africa	53.5	27.0	80.5
South Asia	83.3	1.8	85.1
North and Central Asia	91.6	120.1	211.7
Southeast Asia	20.0	***[z]	20.0
Europe	7.8	22.9	30.7
Australasia	17.4	340.0	357.4

[z] n/a: not applicable

Thirty years later, these figures as reported by Szabolcs (1989) have not been reduced, but in fact have rather expanded under more intensive and increased cultivation to provide food security for an ever-increasing population. Globally, over 4 000 000 km^2 is now being estimated to be affected to some extent by salinity (FAO Statistics, 2006). In addition, under the imminent threat of climatic change, during the last decade, most of the highly affected areas in general have experienced a below average rainfall and/or more erratic rainfall patterns. This trend, together with non-sustainable production practices in other areas, has resulted in salinity to intensify and expand at a rapid rate year after year, to the extent where salinity threatens agricultural crop production today on a worldwide scale. The current, bleak forecast is that by 2050, 50% of the world's arable land will be affected by salinity (Bartels and Sunkar, 2005).

3.1 Salinity in West Asia (Middle East)

Salinity is the first and paramount problem currently facing a crop farmer in the west Asia region, although the severity may vary from one region to another.

Fig. 1. The map of the Middle Eastern region, also showing the position of Jordan as an important country for fresh produce in the region.

3.1.1 Lebanon, Albeqaa region

The Al Beqa region is one of the prime potato producing areas in the Middle East. Soils from this region has a relatively high pH of up to 8.9, together with a similarly high EC and $CaCO_3$ percentage of 22-30% (Table 4).

Table 4. Soil analysis report from Al Beqa area, Lebanon (American University of Beirut: http://www.aub.edu.lb/fas/crsl/Pages/index.aspx).

Mineral element	Content range (%^{z} or mg.kg^{-1})
P	48-70
K	240-550
Na	55-80
Fe	17-30
Cu	8-13
Mg	8.6-14
Mn	35-42
Zn	35-48

$CaCO_3$	22-30
Other soil parameters	
EC ($\mu S.cm^{-1}$)	600-780
pH	7.8-8.9

3.1.2 Syria, Coastal region-Lattakia

The Lattakia area in Syria is considered as some of the most important agricultural production areas in the country, mainly because of extensive tunnel production of about 100 000 tunnels with indeterminate tomato and parthenocarpic cucumbers varieties. A soil analysis report obtained from four sites, at two soil depths (0-30 cm) and (30-60 cm), provide evidence of high pH soils together with relatively high EC for some areas (Table 5).

Table 5. A soil analysis report of four sites in the Lattakia area of the coastal region of Syria (Ministry of Agriculture labs – Lattakia - Syria).

Depth	Area#	EC^z	pH	$CaCO_3$	OM	N	K	P	Sand	Silt	Clay
		$dS.m^{-1}$	KCl	$g.100g^{-1}$	%	ppm^y	ppm	ppm	%	%	%
0-30	A1	2.39	7.27	34.0	1.89	101	807	58	20	18	62
0-30	A2	1.86	7.42	19.0	0.85	71.4	1000	91	16	22	62
0-30	A3	0.63	7.51	4.0	2.45	6.25	577	82	32	22	46
0-30	A4	1.36	7.82	7.0	1.48	0.008	580	54	30	42	28
0-60	A1	2.55	7.66	24.0	0.47	0.041	317	14	28	18	54
0-60	A2	2.37	7.53	19.0	1.23	71.2	308	11	16	18	66
0-60	A3	0.88	7.62	1.3	4.30	192	192	11	26	22	58
0-60	A4	0.82	7.92	0.7	0.007	200	200	9	26	16	58

^zEC_w = electrical conductivity of the irrigation water at 25 °C; ^{y} ppm: parts per million

3.1.3 Saudi Arabia – Hail – Leha Agricultural Company

The Hail region in Saudi Arabia is recognized as one of the top potato, onion and wheat production areas in the Middle East. Still, salinity is a major problem in these soils where saline irrigation water sources are mostly used. Table 6 provides a summary of the status of soils during 2010, a period when a high reduction in potato production per unite area was experienced (report from Leha Agricultural Company, Appendix A). Results indicated a soil pH of 7.6, with EC values of 0.98 $mS.cm^{-1}$, together with high contents of calcium (Ca^{2+}), chloride (Cl^-), sodium (Na^+) and bicarbonate (HCO_3^-). Low quality tubers was produced which led to a high rejection rate by processing factories due to substandard quality. Soil salinity was identified as the main cause of the low quality that limited production.

Table 6. Soil analysis report from Leha farms – Hail – Saudi Arabia (Appendix A).

Mineral compound	Concentration	Mineral compound	Concentration
	mmol.L^{-1}		µmol.L^{-1}
N	3.254	Zn	0.291
P	0.016	Mn	1.110
K	0.545	Cu	0.409
Mg	1.497	Fe	1.504
Ca	1.569	B	19.889
Na	3.641	Al	5.041
Cl	3.884	Mo	0.052
SO_4	0.742		
HCO_3	2.280		
Other soil parameters			
EC^z (dS.m^{-1})	0.98	pH (H_2O)	7.6

^{z}EC$_w$ = electrical conductivity of the irrigation water at 25 °C

3.1.4 Jordan Valley

Jordan soils are well known of their high content of calcium carbonate, sodium and chlorine. Giel and Bojarczuk (2010) stated that the addition of calcium carbonate to their growing medium increased the soil pH, but limited the activity of acid phosphates. Grattan and Grieve (1999) stated that plant deficiencies with respect to several nutrients along with nutritional imbalances may results from the higher concentration of Na^+ and Cl^- in soil solution due to competition between ions for uptake (Na^+/Ca^{2+}; Na^+/K^+; Ca^{2+}/Mg^{2+}; Cl^-/NO_3^-). Mineral analysis of soil samples collected from one of the major banana nurseries in Jordan showed the EC to exceed 2dS.m^{-1}, together with a relatively high Cl^- and $CaCO_3$ (Table 7).

Table 7. Soil analysis report from a major banana production unit, South Shounah, Jordan valley, in Jordan. Analysis done by ACSE (2012).

Compound (unit)	Concentration
N (%)	0.03
P (ppm) ^{y}	17.69
K (ppm) ^{y}	219.5
$CaCO_3$ (%)	30
Ca (exchangeable; meq.100g^{-1})	0.04
Na (exchangeable; ESP %)	6.1
Cl (ppm) ^{y}	110
Other soil parameters	
EC (paste extract; dS.m^{-1})	2.3
pH (paste extract)	7.85

^{z}EC$_w$ = electrical conductivity of the irrigation water at 25 °C

^{y}ppm= parts per million

4. Impact of salinity on plants

Salinity, whether present in irrigation water or in soils, and where an EC of 2 dS.m^{-1} is exceeded, will impact negatively on plant growth. Salinity causes not only differences between the mean yield and the potential yield, but also causes yield reduction from year to year (Hussain et al., 2009). Soil salinization is a major factor contributing to the loss of productivity of cultivated soils (Machado and Serralheiro, 2017). When salinity reaches values of above that of 2 dS.m^{-1}, the soil EC is considered harmful to a wide range of commercial crops, as water movement as well as the absorption and movement of many essential nutrients such as K, Ca and N are disturbed.

The effect of salinity is usually first observed in the nursery with transplant during the establishment stage, as root hairs are more compromised by salinity than the root structure itself. A significant quick decrease in root growth as a response to salinity after planting was reported by Cramer et al. (1988). In addition to affecting root hair development and root growth, salinity also impacts on vegetative growth, such as causing white margins on the leaves of indoor, parthenocarpic cucumber when planted in desert sand. Furthermore, salinity induce stunted growth observed as rosette-shaped tips in most crops, mainly due to competition between cations that result in low zinc uptake (personal observation). Flowering and fruiting can be significantly affected by salinity, mainly due to low floral initiation resulting from the inhibition of phosphorous uptake. This isfollowed by poor fruit set and/or the abortion, or the production of low quality fruit displaying various physiological disorders such blossom end rot (BER) Hossain and Nonami (2012). Even seed germination is negatively affected by the salinity of either the growth medium and/or irrigation water (Cordazzo, 1999).

According to Carvajal et al. (1999), Grattan and Grieve (1999a) and Yeo (1998), the direct effects of salts on plant growth may be divided into three broad categories: (i) a reduction in the osmotic potential of the soil solution that limit available water, (ii) a deterioration in the physical structure of the soil, and thereby reducing water permeability and soil aeration and (iii), where an increase in the concentration of certain ions have an inhibitory effect on the plant metabolism by causing specific ion toxicity and induced mineral nutrient deficiencies. However, the relative contribution of osmotic effects and specific ion toxicities on yield are difficult to quantify in most crops, and Dasberg et al. (1991) reported that yield losses from osmotic stress could be significant before foliar injury become apparent.

4.1 Soil Salinity – a physiological over view

In order to understand the effect of salinity on plants, the internal plant physiological responses to salinity, and to the components of soil salts that cause salinity in the first place, mainly that of Na^+ and Cl^-, should be considered.

Under normal (non-saline) conditions, the cytosol of higher plants usually contains a ratio of 100 mM K and less than 10 mM Na, allowing plant enzymes to function optimally. However, when being exposed to saline conditions, Na and Cl concentrations can reach up to 100 mM (millimolar) in the cytosol where it competes with K for binding sites, thus cause toxicity, in particular, protein denaturation and membrane destabilization, as Na is a more destabilizing ion than K (Taiz and Zeiger, 2015). In addition, Na can also compete with Ca at cell wall binding sites leading to a reduction in Ca activity in the apoplast and resulting in increased Na influx via none-selective cation channels (Epstein and Bloom, 2005).

Soil salinity always leads to a reduction in soil water potential, while at the same time this reduces the ability of the plant to access water required for normal growth and development. Physiologically, a reduction in free water will lead to a decreased cell rate expansion in growing tissues. This in turn will result in slower leaf formation, and, will lead to a reduction in the flow of assimilates from these sources to the growing sink tissues, in either the roots or the developing leaves. Munns and Sharp (1993) however concluded that leaves are usually more affected by salinity than roots, probably due to high transpiration rates.

With increasing salinity, more Na^+ and Cl^- ions enters the plant, and reach toxic levels in the older leaves. This toxicity, in addition to decreased leaf area, will affect the translocation of carbon compounds to areas of active growth, such as younger leaves, resulting in death before seed development and the completion of the life cycle can occur. Plant growth and development usually are programmed to produce new leaves at a higher rate than the death rate of mature leaves, however under salinity stress, the death of older leaves will exceed the generation of new ones, and the end of the life span of the plant will be reached earlier. Cell death ascribed to the accumulation of salts in leaves occur when the salt concentration exceeds the ability of cells to compartmentalize salts within the vacuole.

The effect of salt salinity at a physiological level is mostly either directly due to diffusion limitations in the stomata and mesophyll or by decreasing the photosynthetic rates. However, it can also manifest itself indirectly by causing oxidative stresses through the superimposition of multiple stresses (Chaves et al., 2009). Kamal Uddin et al. (2011) reported a significant decrease in chlorophyll content and a decreased the K/Na ratio under saline conditions in 16 turf grass species when planted in plastic pots filled with sand and peat (9:1 $^{v}/_{v}$) and then irrigated with sea water of different salinity levels.

4.1.1 Mechanisms of salt tolerance in plant cells

Many plants that are classified as either salinity tolerant or resistant has over time developed several mechanisms to adapt their growth in saline soils conditions. Three basic salinity plant responses that can be considered to be tolerance mechanisms have been proposed by Munns and Tester (2008). The first mechanism is ion exclusion which can be explained as the net exclusion of toxic ions from the cell; a second mechanism refers to tissue tolerance through the compartmentalization of toxic ions into specific tissues, cells and subcellular organelles; while thirdly, ion-independent tolerance can occur which refers to the maintenance of growth and water uptake, independent of the extent of sodium accumulation in the plant.

In addition to plant tolerance mechanisms, plant defence strategies can also assist in completing the plant life cycle under saline soil conditions. One such as an important strategy is the growth rate adjustment. To illustrate: Watad et al. (1983) reported that fresh weight accumulation of tobacco cells exposed to salinity was only about half of the accumulated fresh weight recorded for the control treatment with no salinity. Similarly, Binzel et al. (1987) concluded that a maximum volume of 20% compared to the control could be achieved for tobacco leaves exposed to salinity.

An important line of defence of plants against salinity is osmotic adjustment. Heyser and Nabors (1981) stated that, as a response to salinity, cells show osmotic adjustment by increasing their internal potential to compensate for the decreased water potential. Turner et al. (2007) reported that the success of osmotic adjustment lies in the ability to postpone dehydration in a water-limiting environment, while at the same time maintaining cell turgor and critical physiological processes as water deficit develops under conditions of drought and salinity.

An additional defence against salinity is that of root extrusion of salts, prevent salts from entering the root tissue. Roots use energy for the extrusion process of Na^{+}, whereas Cl^{-} is extruded by the negative electric potential across the cell membrane (Taiz and Zeiger, 2015). The movement of Na^{+} into leaves is further controlled by limiting the absorption of Na^{+} from the transpiration stream (xylem sap) during its movement from the roots to the shoots.

Chen and Jiang (2009) described the mechanism of osmotic adjustment to be controlled by either organic solutes like glycine betaine, proline, sugars, or inorganic ions such as K^{+}, Ca^{2+} and Na^{+}. Marti et al. (2011) studied the response of mitochondrial thioredoxin PsTrxo1 antioxidant enzymes and respiration to salinity in pea (*Pisum sativum* L.). Results from this study indicate PsTrxo1 to be an important component of the defence system that is being generated with an increase of NaCl in the mitochondria, where it provides protection to mitochondria from oxidative stress. This mechanism could also be shown to be effective with similar antioxidant systems such as Mn-SOD, AOX and Prxll F. Chutipaijit et al. (2011) reported a higher content of proline and anthocyanin in one of the salt tolerance rice genotypes (*Oryza sativa* L. spp. Indica). It was concluded that accumulation of anthocyanin and proline was directly associated with cellular protection and salt detoxification of salinity-resistant rice seedlings.

The role of abscisic acid (ABA) in freezing, salt and water stress has clearly identified it as as a stress hormone. Plant response to salinity is thus also considered to be mediated through increasing ABA synthesis. ABA levels have been shown to increase with up to 50 times in leaves under drought and/or saline conditions (Bohra et al.,1995). Such increased levels effectively reduce water loss by transpiration through controlling the stomata behaviour. In a study by Zhang et al. (2006) the rapid production of ABA in response to drought and salt stress is reported and considered essential in the integration of the plant response to these stress factors.

Supporting this hypothesis Saeedipour (2012) shown a differential sensitivity to ABA between tolerant and sensitive cultivars of indica rice (*Oryza sativa* L.) leaves. This study concluded that the difference in tolerance levels to saline stress to be directly related to their different capacity of ABA synthesis under stress conditions.

4.1.2 Plant adaptation to salinity stress

Various plants have acquired mechanisms that allowed for adaptation to saline soils. Munns (2002) reported leaf expansion and growth in saline soil, when considered over a time scale of a number of days, did not respond to an increase in leaf water status, but were rather controlled by hormonal chemical signals that were produced from the roots in either dry or saline soils. ABA was identified as the major component of this signal as it was found at elevated levels in the xylem sap after drought, and similarly so, after salinity stress (Munns and Cramer, 1996). Thus, the mechanisms that permit growth under saline soil stress conditions are now known to be of a hormonal nature and not that of water relations directly as the controlling factor.

In halophytes, turgor maintenance and osmotic adjustment is considered an important trait required for adaption to saline conditions. Yet, whilst this trait can assist the plant to overcome salinity and/or drought conditions, a metabolic cost is involved. To illustrate: under non-saline conditions, approximately 7 ATP moles are required to accumulate 1 mole of NaCl in leaf cells, while under saline conditions the amount of ATP required to synthesize one mole of organic compound is much higher (Raven, 1985). Thus, while ameliorating of salinity occur at the expense of plant growth, at the same time it ensure survival under periods of high saline conditions.

The major challenge within the cell of a plant exposed to salinity is to maintain both Na^+ and Cl^- concentrations in the cytoplasm below 10-20 mM, which are considered toxic levels (Munns and Tester, 2008). The main mechanism to achieve such required low cellular levels of salts involves the exclusion of Na^+ and Cl^- by the roots. This exclusion can occur through two major processes: either by tightly controlling uptake from the soil by forming a virtual barrier between the epidermis and the soil, or by regulating the movement of both Na^+ and Cl^- in the xylem.

Table 8 lists the major traits involved in adaptations to soil salinity in wheat and barley that are selected by breeders to produce saline resistant varieties. The importance of each trait in production and to what extent the plant complete its life cycle normally under soil salinity conditions is also indicated (Colmer et al., 2005).

The most effective characteristic amongst the various plant physiological traits which may allow production of crops under soil salinity stress is the Na^+ exclusion ability by the roots. In addition, plant ability for K^+/Na^+ discrimination like in wheat diploid cultvars along with osmotic adjustment are also recognized as key mechanism in coping with salinity (Stewart et al., 2010).

The physiological effect of salinity on two banana cultivars, 'Williams' and 'Grand Nain' was investigated by Abd El-Latef et al. (2007). Results from this study showed that the levels of foliar photosynthetic pigments (chlorophyll A, chlorophyll B and carotenes), also as well as that of proline and mineral nutrients like N, P, K, Ca, Mg, Fe, Mn and Zn were significantly affected by salinity. Photosynthetic pigments and all of the above nutrients except for Ca showed levels that decreased with increasing salinity, while proline, Ca and Na levels increased with increasing salinity. 'Grand Nain' plants were showing significantly higher values for both vegetative growth as well as chemical composition when compared to the cultivar 'Williams'.

In research by Hossain and Nomani (2012), the physiological response of tomato to Ca-induced salt stress when grown in a hydroponic system was recorded through reporting on parameters such as fruit growth rate, water status, cuticle permeability and induction of blossom end rot (BER). Results suggested that the deposition of cuticular wax on fruit surfaces was enhanced by salt stress conditions. Interestingly, BER was still observed despite the presence of high calcium levels in the solution, implicating that Ca deficiency was not the only cause of BER in tomato, but that the fruit tomato is vulnerable to salt stress throughout all its developing stages.

Finally, Acosta-Motos et al. (2017) stated that the observed decrease in plant growth may also be considered as a mechanism to minimise water loss by transpiration. Such an adaptation to salinity could include an increased root to shoot ratio. A greater root proportion in the ratio when under salt stress can favour the retention of toxic ions, which can be an important adaptation for plant resistance/survival under saline conditions.

Table 8. Key traits for salt tolerance in wheat and barley. Recommendations on approaches, plant stages and other considerations for screening are listed (adapted from Colmer et al. 2005).

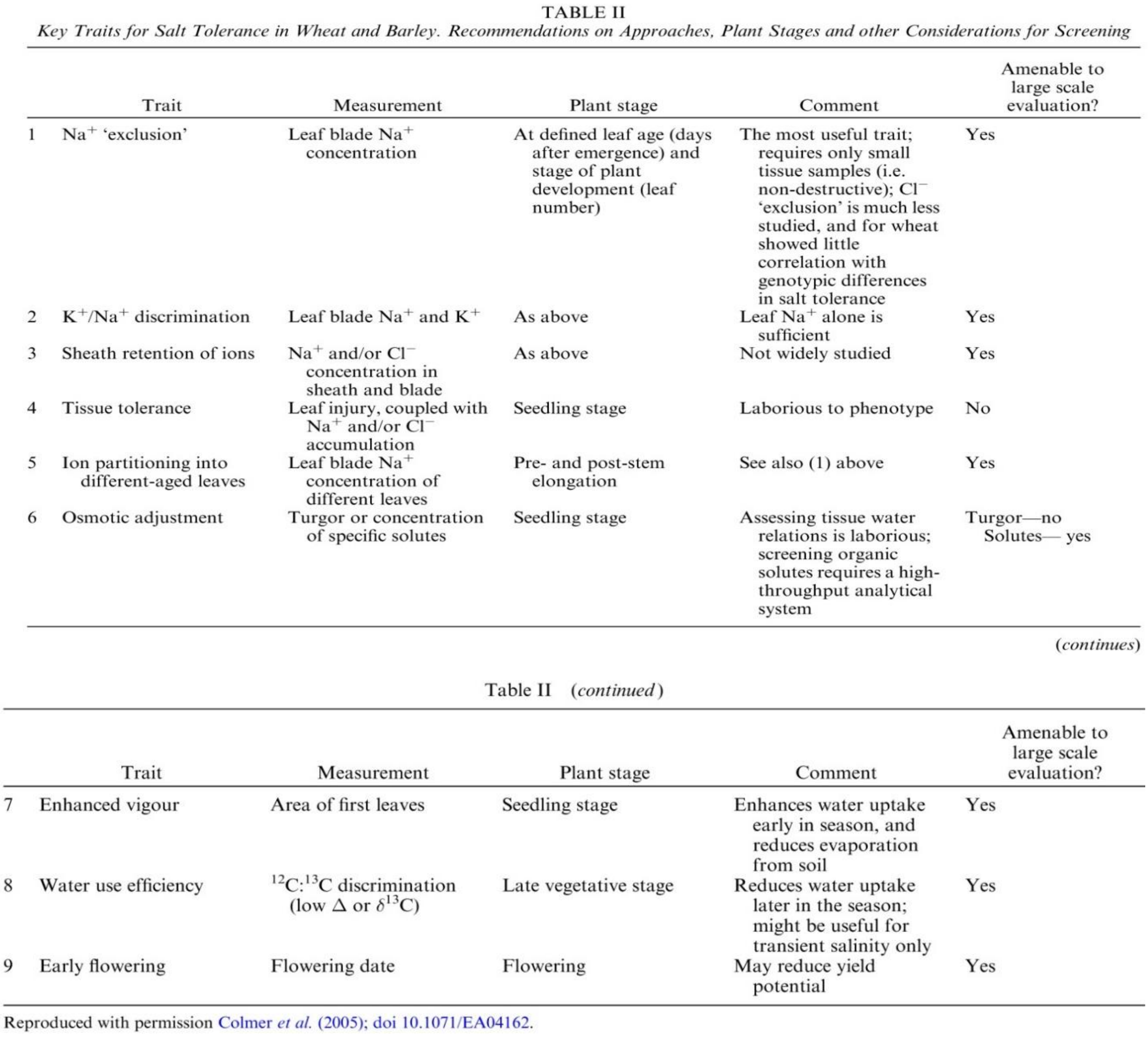

TABLE II

Key Traits for Salt Tolerance in Wheat and Barley. Recommendations on Approaches, Plant Stages and other Considerations for Screening

	Trait	Measurement	Plant stage	Comment	Amenable to large scale evaluation?
1	Na^+ 'exclusion'	Leaf blade Na^+ concentration	At defined leaf age (days after emergence) and stage of plant development (leaf number)	The most useful trait; requires only small tissue samples (i.e. non-destructive); Cl^- 'exclusion' is much less studied, and for wheat showed little correlation with genotypic differences in salt tolerance	Yes
2	K^+/Na^+ discrimination	Leaf blade Na^+ and K^+	As above	Leaf Na^+ alone is sufficient	Yes
3	Sheath retention of ions	Na^+ and/or Cl^- concentration in sheath and blade	As above	Not widely studied	Yes
4	Tissue tolerance	Leaf injury, coupled with Na^+ and/or Cl^- accumulation	Seedling stage	Laborious to phenotype	No
5	Ion partitioning into different-aged leaves	Leaf blade Na^+ concentration of different leaves	Pre- and post-stem elongation	See also (1) above	Yes
6	Osmotic adjustment	Turgor or concentration of specific solutes	Seedling stage	Assessing tissue water relations is laborious; screening organic solutes requires a high-throughput analytical system	Turgor—no Solutes— yes
7	Enhanced vigour	Area of first leaves	Seedling stage	Enhances water uptake early in season, and reduces evaporation from soil	Yes
8	Water use efficiency	^{12}C:^{13}C discrimination (low Δ or $\delta^{13}C$)	Late vegetative stage	Reduces water uptake later in the season; might be useful for transient salinity only	Yes
9	Early flowering	Flowering date	Flowering	May reduce yield potential	Yes

(*continues*)

Table II (*continued*)

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4.2 Soil Salinity and nutrients uptake

As salinity increase in the growing medium, soils become frequently characterized by extreme ratios of Na^+:K^+, Na^+:Ca^{2+} and Cl^-:NO_3^-, leading inevitably to nutrient imbalances and/or deficiencies (Schmidhalter et al., 1999). Most macro- and micronutrient content decrease inside the different plant parts (roots and shoots), with increasing NaCl concentration in the growth medium. As N, Ca, and K is recognized as the three most important nutrients in addition to P for the plant to ensure strong establishment, good vegetative growth and high production of products of superior quality, a brief overview of the role of these elements is provided.

4.2.1 Nitrogen

Salinity may not affect nitrogen (N) uptake directly, but has a cellular effect on N^+ assimilation as well as on the enzymes associated with N conversion to its sites of transport and storage. Whenever salinity increase, the content of free amino acids is decreased in crops like wheat, due to decreased activity of nitrate reductase, a critical enzyme for the conversion of nitrate into ammonium (El-Leboudi et al., 1997). Albassam (2001) confirmed these results in pearl millet where nitrate reductase was similarly affected by salt stress, and led to decreased NO_3^- uptake. Of special interest in this study was that the incorporation of high nitrate (at the rate of 10mM) by fertigation could lower levels of Cl^- and converted the inactive form of nitrate reductase to the active form. Similarly, Qadir and Oster (2004) reported Cl^- uptake in cucumber planted in saline-sodic soils to be reduced when NO_3^- was added. In another application, half the NO_3^- was replaced in the solution with NH_4Cl, however, when exposed to this treatment accumulation of Cl- was enhanced. Alternatively nitrate application was also found to reduce the incidence of injury through the subsequent reduction of Cl^- toxicity symptoms in certain crops like melons and tomatoes, Kafkafi et al. (1992). Finally, Bar et al. (1987) reported that low nitrate concentration in soil led to the absorption of Cl^- in higher quantities when compared to those absorbed when nitrate concentration in soil was elevated. Thus under saline soil conditions the preferred form of nitrogen to reduced Cl^- toxicity is clearly nitrate.

4.2.2 Calcium

Calcium (Ca) is commonly found in many mineral soils, especially in those of the Middle East where it occurs in very high percentage as carbonates, which is a relatively insoluble form. As Ca^{2+} deficiencies are common on almost all crops, Ca^{2+} fertilizers are routinely applied in various formulations: either as a remediation of salinity or as a type of soil conditioner. Under these conditions, Ca^{2+} will replace the Na^+ in the soil and Na^+ will be partially and temporarily leached from the soil solution during Ca-enriched fertigation.

Qadir and Oster (2004) studied the reclamation of saline-sodic soils that was driven by providing a source of Ca^{2+} to replace excess Na+ from the cation exchange sites on the clay particles. The replaced Na+ was leached from the root zone through excess irrigation. Grattan and Grieve (1999b) stated Ca^{2+} availability together with Ca^{2+} transport and mobility to growing regions of the plant to be limited a saline medium that was generated by the addition of Na^+ salt, thus seriously be affecting the quality of vegetative and reproductive organs.

4.2.3 Potassium

Potassium (K) is a critical element due to its role in the activation of more than 50 enzymes in the plant, and its regulatory function in the opening of leaf stomata and maintaining the cell turgor (Marschner, 1995). K^+ is negatively affected by soil salinity, as Na^+ has a strong ability to compete with K^+ for binding sites that are important for cellular function, resulting in metabolic toxicity of Na^+ (Tester and Davenport, 2003). Thus, the presence of high levels of Na, with high Na:K ratios as a consequence will result in disturbing various enzymes activities in the cytoplasm. In addition, protein synthesis will also be disrupted, as this process requires high K^+ concentrations to facilitate the binding sites of tRNA to the ribosomes.

K^+ in the formulation of KNO_3 is considered an ideal fertilizer to be integrated in a fertigation program designed to produce best forms of N^+ and K^+ for saline soils conditions, as the ratio of these two nutrients within KNO_3 is similar to the optimal ratio inside many crops (Achilea and Barak, 1999).

4.2.4 Phosphorous

Phosphorous (P) is considered one of the first elements that are usually affected by salinity, therefore P deficiency usually becomes very obvious under saline conditions. Awad et al. (1990) found that the P concentration in the youngest, mature tomato leaf had to be increase from 58 to 77-97 $mmol.kg^{-1}$ of dry weight when NaCl concentration was increase gradually from 10 to 50-100 mM respectively in order to obtain 50% of the expected yield. This demonstrated that the higher the salinity, the more P is required to overcome the reduced uptake driven by the increasing salinity.

In contrast, a study done by Gunes et al. (1999) indicated that salinity increased the P^+ uptake as plants grown in saline soils were found to be more sensitive to P toxicity. However, Zribi et al. (2011) stated the interactive effects of salinity and phosphorus on growth, water relations, nutritional status and photosynthetic activity in barley (*Hordeum vulgare* L. cv. Manel), not to be additive since the response of plants to combined salinity and P deficiency was similar to that of plants grown under Pdeficiency alone.

5. Salinity effect on selected crop plants

Numerous trials have been done worldwide to evaluate the effect of salinity on a wide range of plants species, but all reaching more or less the same conclusion: plants are negatively affected by salinity. In one such a trial by Awada et al. (1995) the effect of salinity on the common bean (*Phaseolus vulgaris*) were studied after exposing seedlings to NaCl, or Na_2SO_4, or a combination of $CaSO_4$ or $CaCl_2$. Results consistently showed that as Na concentration was increased relative to the dry weight of the plant, the number of root nodules and together with the number and weight of pods would decrease dramatically. In barley, generally considered a salt tolerant crop, production was still progressively reduced when three varieties were exposed to four increasing NaCl levels (Javed et al., 2003). Traits like spike length, number of spikelets per spike, fertile tillers per plant, grain yield and 100 grain number were all negatively affected by salinity although the genotypes varied in their responses to saline conditions.

5.1 Salinity effect on banana

Banana is one of the major crops grown worldwide and widely considered to be of high nutritional importance. In the Middle East region banana is well-known as a crop that cannot tolerate irrigation water with a high salt content or highly saline soils. An EC value for optimum banana growth is estimated to be between 1.8 to 2.2 $dS.m^{-1}$. Salinity, either in soils or irrigation water, will affect the vegetative growth traits as well as the yield and quality of banana fruit.

In a trial on ‘Nanicao’ (Cavendish group) by Filho et al. (1995) in Brazil, salinity was found to affect the root growth, even before any salinity stress symptoms on the plant could be observed (Fig. 2). Soil salinity expressed by increased EC in $dS.m^{-1}$ was also found to affect growth parameters like plant height, circumference and diameter (Fig. 3).

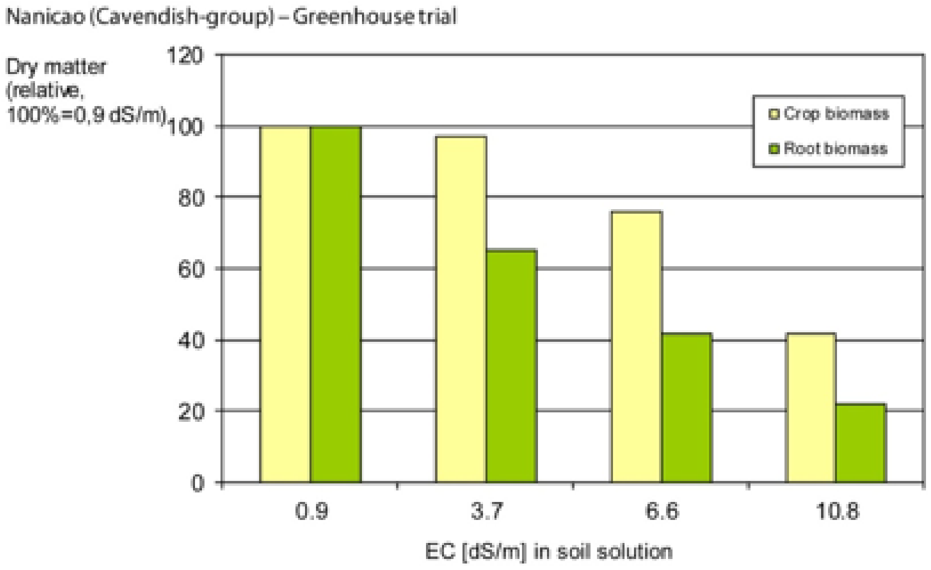

Fig. 2. Salinity in soil result in crop and root biomass reduction of 'Nanicao' banana, with salinity affecting root growth before crop stress is visible (Filho et al., 1995).

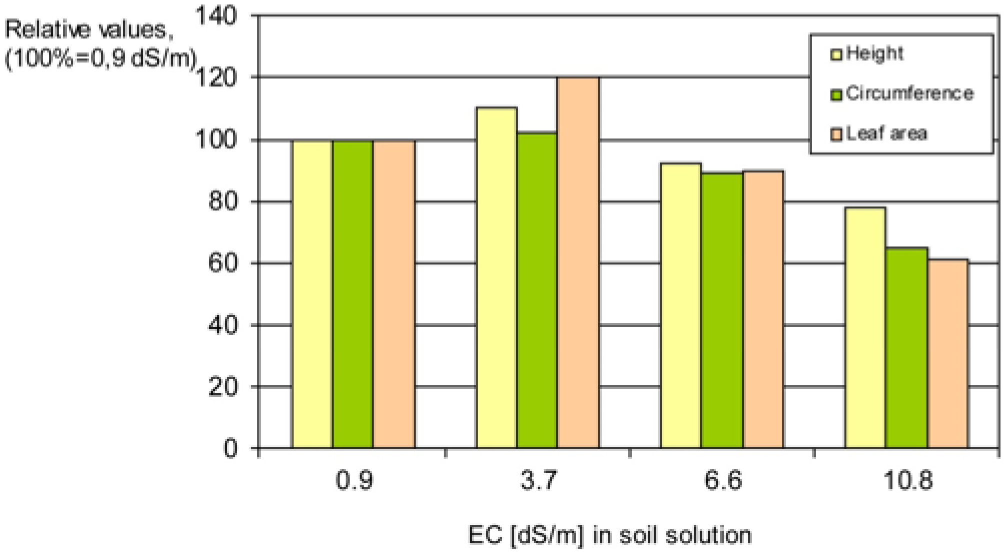

Fig. 3. Salinity of soil solution reduce vegetative growth in 'Nanicao' banana (Filho et al., 1995).

Salinity has thus repeatedly been observed to reduce banana production by decreasing the root biomass, leaf surface area, plant height and circumference. All the trials consistently confirmed that salinity of the growth medium has a strong negative correlation with growth and production.

In a greenhouse study by Gomes et al. (2002) in the northern region of Brazil, five banana cultivars (‘Pacovan, ‘Nanicao’, ‘Caipira’, ‘FHIA 18’ and ‘Calcutta’) were exposed to three concentrations (0, 50 and 100 mM respectively) of salinity generated by NaCl, whilst each treatment consisted of eight replicates. Results showed that after 21 days, the Na and Cl concentrations increased corresponding in all cultivars according to the NaCl concentration gradient. Whilst the Cl concentration was similar in the leaf tissue, pseudo stem as well as in the root and rhizome at each respective NaCl level, the Na concentration of ‘Pacovan’, ‘Nanicao’ and ‘FHIA 18’ were found in higher concentrations in the root and rhizome for the plants treated with 100mM NaCl. The highest Na concentration was found in the leaf of ‘Calcutta’ along with a responding decline in K concentration. In general, treatment of plants with a 100mM NaCl solution resulted in a reduced of dry weight of the leaf of about 70% along with a reduction in the leaf area of 50%, although ‘Pacovan’ showed the lowest decrease of leaf dry weight of about 40%, together with the lowest reduction in leaf area of 29%.

A study was conducted in Egypt to compare the effect of salinity on the two banana varieties ‘Gran Nan’ and ‘Williams’ under green-house conditions when grown in pots filled with a clay:sand mixture at the ratio of 2:1, whilst being fertigated with nutrient solutions at saline concentration with NaCl at either 2000 or 3000 mg.L^{-1}. Results from this study showed that, in most cases, ‘Grand Nan’ plants showed significantly higher values of both vegetative growth (pseudo stem length and diameter, leaf number and colour, and fresh and dry weight of leaf, pseudo stem corms and roots) and in its chemical composition as pertaining to photosynthetic pigments, proline content and leaf mineral content compared to ‘Williams’. Except with regard to senescence rate as well as leaf Ca and Na content, the opposite was true for the ‘Williams’ (Abd El-Latef et al., 2007).

Ikram-Ul Haq et al. (2011) studied certain growth related attributes of micro-propagated banana plants under different salinity levels. In this study photosynthetic pigments such as total carotenoids were found to increase whilst the chlorophyll content was decreased with salinity. In addition, the total protein as well as carbohydrate content was also significantly decreased under more saline conditions. Finally, a negative relationship between saline stress and in vitro plant micro-propagation was established.

5.2 Salinity effect on tomato

For tomato, the dry weight of many plant parts has been reported to be reduced as a response to the gradual increase of NaCl concentration in the root growth medium. El Fouly et al. (2002) found that uptake of Na markedly increased with the increasing of NaCl in the growth medium, with an accumulation from 1000 mg.L^{-1} to 3000 mg.L^{-1} of NaCl. In addition, almost all the micronutrients uptake was negatively affected by the increasing NaCl concentration. To the contrary, spraying tomato seedlings with a micronutrients formulation that contains Fe at 2.8%, Zn at 2.8% and Mn at 2.8% respectively at the dose of 1.5 ml.L^{-1} facilitated and increased an increasing dry weight of the various plant organs. A similar case was reported by El-Sherif et al. (1990) where the Zn application improved the growth of tomato plants cultivated on saline soils.

The extent to which the response to salinity within a crop type is influenced by genetic variation and to what extent varieties differ in their tolerance to salinity should always be considered. Foolad and Lin (1998) stated that a large genetic variation in tolerance to salt levels exist among tomato different genotype. Ironically, salt tolerance breeding programs has been restricted by the complexity of this trait, mainly though a lack of understanding the mechanisms, together with genetic and physiological bases on which these tolerance traits are established.

Hartz (1990) stated that most commercial cultivars of tomato is sensitive to even moderate levels of salinity up to 2.5 dS.m^{-1}, after which significant reduction in yield of these varieties is reported. In support of this statement, Kaveh et al. (2011) concluded that, according to germination and seedling emergence for tomato, germination percentage and germination rate, for all lines, was most optimum at the lowest level of salinity 0.5 dS.m^{-1}. In addition, the final germination percentages decreased and the germination rate was delayed as salinity increased. As for yield, Mass and Hoffman (1977) reported tolerance to soil salinity of tomato of up to 2.5 dS.m^{-1}, with a reduction of 9.9 % in production for each unit increase of salinity above the reported threshold rate. Furthermore, Ayers (1977) found that the use of irrigation water with the EC's of 1.7, 2.3, 3.4 and 5.0 dS.m^{-1} reduced production with percentages of 0, 10, 25 and 50 % respectively.

Research by Boamah et al. (2011) on tomato showed that plants that were treated with well water with a EC_w of 0.07 dS.m^{-1} produced the highest yield, followed by the plants treated with pond water with an EC_w of 0.25 dS.m^{-1}, whereas the lowest yield was obtained from the plants treated with tap water with an EC_w of 0.02 dS.m^{-1}. The highest flowering rate was also obtained from the plants treated with well water. Since the EC is an indication of total salts (promotive and inhibitory), this could explain why the tap water produced the lowest yield.

Research conducted in Tunis by Kahlaoui et al. (2011) included a field experiment where the effect of drip irrigation and surface drip irrigation with saline water on three tomato cultivars 'Rio Tinto, 'Rio Grande' and 'Nemador' were studied to elucidate physiological responses from each variety to salinity conditions. The study was performed in clay soil with three irrigation schedulings at either 100%, 85% or 70% of total crop water requirement respectively. Growth parameters recorded included the leaf area, chlorophyll content and mineral composition of above- and below ground components. Results showed that petioles, stems and roots were significantly affected by the different irrigation treatments, whereas the fruit organs were less affected. Plants exposed to drip irrigation showed a high accumulation of Na and Cl, along with a reduction in the content of Ca, Mg, K and P. The accumulation of Na and Cl however varied between varieties.

Cantore et al. (2008) compared the marketable yield of the three varieties of tomato ‘Dart’, ‘Robin’ and ‘Tomito’ after being treated with three levels of saline water at 0.5 (control), 4 and 8 $dS.m^{-1}$. The varieties ‘Tomito’ and ‘Dart’ followed the Mass and Hoffman (1977) model, where an approximate 10% reduction in production occurred for each unit increase of salinity above the threshold level of salinity. However ‘Robin’ appeared to have a lower salinity tolerance compared to the other two cultivars evaluated, based on a lower mean fruit weight recorded. Both ‘Tomito’ and ‘Robin’ showed an increase in the ratio of blossom end rot (BER) from 0.5% at an EC of 0.5 $dS.m^{-1}$ to 7.7% at an EC of 4 $dS.m^{-1}$, however this trend was not statistically significant at the 5% confidence level.

6. Nutrient formulation as a strategy to ameliorate soil salinity

Salinity can vary extensively between different sources and in severity so that crop production in many cases are limited to the planting of only a few selected crops, or in some severe cases no crop production, in any form, is possible.

However, where salinity is not that severe or totally limiting, farmers have acquired through experience and over time, various practices to reduce salinity through methodologies that permit reasonable crop production under saline stress conditions. In Egypt, for example, the underground drainage channels are used throughout the Delta region to remove salts from the soil through irrigation from the Nile river (Norris, 1935). On the other hand, in GCC (Gulf Council Countries) like in Saudi Arabia and Emirates, famers employ heavy irrigation with good quality water at plantings on sandy soils, as this assists in leaching salts from the soil. In addition to this practice, various well-known chemicals mostly based on calcium oxide, humic acid and seaweed extracts are known as soil conditioners and maybe used to repel Na from the soil solution in the rhizophere. In other countries like in Jordan, where soil salinity borders at the threshold where production is negatively affected, farmers have adopted the practice to mix the soil with conditioning media like volcanic stones or coco peat or may even replace soils completely with these media to avoid salinity.

The inclusion of soil conditioners are a very common practice in Jordan, Syria, Lebanon and Iraq in order to secure acceptable levels of production and to ensure the completion of the life cycle of planted crops, with either no or low levels of physiological disorders detected. An alternatively strategy to adjusting the growth media to overcome salinity stress could also be to provide an optimum mineral nutrient formulation, containing K, N and Ca, which can be taken up with high efficiency even under saline conditions.

6.1 Salinity ameliorated by potassium (K^+) formulation

K^+ uptake within the plant is usually mediated through K^+ specific channels (Wang et al., 2009). Under salinity stress conditions, Na^+ competes with K^+ for these channels and the K^+/Na+ ratio in the cytoplasm is disturbed. Due to the involvement of K^+ in the activation of more than 60 enzyme systems, it’s role in photosynthesis, the maintenance of cell turgor along with the regulation of leaf stomatal movements, in addition to other functions (Marschner, 1995), such disturbed K^+/Na^+ ratios will mostly certainly affect all these processes inside the plant.

Al-Karaki (2000) stated that salinity tolerance in some plant species is related to aspects of K^+ and N^{a+} uptake and transport. When three levels of salinity generated from NaCl were combined with two levels of K^+ in a fertigation solution for tomato, it was reported that when K^+ is low, different rates of salinity decreased growth rate. However when K+ level was relatively high, the adverse effect of salinity was reduced. Also, under conditions of increasing K^+, the translocation of Na^+ from the root system up to the shoots decreased correspondingly. It is therefore clear that K^+ supply, accumulation and regulation in the plant tissues plays an important role in the plant tolerance to salt stress.

In Israel, Guerrero and Gadban (1996) conducted a study on banana to show the importance of the source of K^+ when producing under saline soil conditions. Results showed that the highest bunch weight was obtained when KNO_3 was used as an exclusive source of K^+. When KNO_3 nitrate was replaced with K_2SO_4, the lowest fruit bunch weight was achieved, with intermediate results obtained when these two potassium sources were mixed in the fertigation program (Table 9; Fig. 4).

Table 9. The effect of KNO_3 application on banana bunch weight, bunch number and yield per hectare when applied under conditions of salinity (adapted from Lahav, 1972).

KNO_3 applied $kg.ha^{-1}.yr^{-1}$	Mean bunch weight kg	No. of bunches $bunches.ha^{-1}$	Yield $MT.ha^{-1}.yr^{-1}$
0	23.3	1650	37.2
500	26.2	1910	47.2
1000	27.2	2000	50.5
2000	26.4	2140	51.5

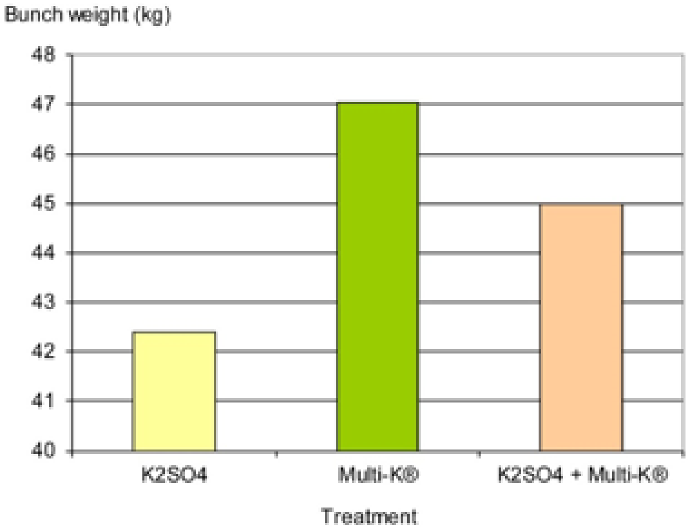

Fig. 4. The effect of different potassium fertilizers on banana yield (kg) when cultivated under saline conditions. Multi-K is potassium nitrate, with K^+ at 13% and NO_3^- at 46% (adapted from Guerrero and Gadban, 1996).

6.2 Salinity ameliorated by nitrogen (N) formulation

Bybordi and Ebrahimian (2011) reported a decrease in nitrate reductase activity in canola due to salinity stress. Reduction in nitrate reductase activity, nitrate content and total nitrogen content because of high salinity levels maybe a physiological response in order to decrease growth and biomass so that the plants can better cope with salinity. The form of the N^+ formulation may play a role in salinity resistance as Alyemeni (1997) reported plants grown in nitrates to be more salt tolerant than those grown in ammonia.

When Arshad and Rashid (2001) cultivated tomato plants on medium and high saline solutions a significant difference in N uptake was noted between treatments, from day 15 and day 20 respectively. Plants treated with medium saline solution had significantly higher N uptake than plants exposed to the high saline solution on days 15 and 20, although no significant difference existed between the two saline treatments from days 25 and onwards. This led to the conclusion that the plants were more successful to adjust and were as such more tolerant to salinity during later stages compared to earlier growth phases.

6.3 Salinity ameliorated by calcium formulation

Salinity stress inhibits Ca^{2+} translocation to the shoot. In addition to this reduction in Ca^{2+}availability Na+ also replaces existing $Ca^{2+}$from the leaf apoplast (Zid and Gringnon, 1985). Making use of this displacement interaction between Na^+ and Ca^{2+}, Ca^{2+} is an important component of soil conditioners which are used commercially to improve the plant performance under saline soils conditions. Displacement of the Na^+ from the soil solution leads to leaching of Na^+ with the irrigation water to layers below the root system zone.

Ali et al. (1988) reported on the use of fertilizer treatments containing Ca^{2+} (N free), calcium nitrates, urea and phosphorous as SSP (single superphosphate) and as TSP (triple super phosphate), and combinations thereof on rice and wheat. In this study calcium nitrates and the TSP combination resulted in a substantial decrease in EC together with a slight increase in pH, and a 24-44% decrease in the exchangeable sodium percentage.

Arshi et al. (2010) discussed the effect of calcium on salinity inhibition of growth, ion accumulation and proline content in *Cichorium intybus* L. (Chicory). NaCl-treated plants experienced decreased shoot length and root length by 35% and 29% respectively at different life stages, while plants treated with $CaCl_2$ showed an increase in root- and stem length by 21% and 24% respectively. One of explanations for this recovery in growth is that calcium ions are well-known to have a regulatory role in metabolism, and may compete with Na^+ for membrane binding sites, subsequently protecting the cell membrane from the negative effect of salinity (Zidan et al., 1990).

On studying the efficiency of calcium in alleviating stress during germination of *Phragmites karka* seeds, Zehra et al. (2012) concluded that salinity, absence of light and high temperature (25/35 °C) reduced germination, while calcium generally reversed this effect, even more so under cooler temperature regimes.

6.4 Salinity ameliorated by the use of compost

The use of various types, formulations and origin of compost has been considered as one of the basic practices available to farmers in many arid areas around the world. The use of compost is especially beneficial when the soil salinity is high, as this practice has proved not only to improve the soil physical characteristics. In addition it adjust the chemical properties of the soil such as the pH, thus assisting in making the nutrients in the soil more soluble and available to the plants under harsh saline soil conditions. In general, the main focus in compost use would be to re-build soil physical and chemical properties and re-establish microbial populations and activity (Hanay et al., 2004).

Sarwar et al. (2008) reported in a study conducted in Pakistan on the effect of compost application in a rice-wheat cropping system on soil physical and chemical properties that the soil fertility can be improved with, with a net improvement in crop productivity. Results from this study showed that soil pH declined, electrical conductivity (EC) increased, while the sodium absorbtion rate (SAR) decreased, due to leaching of Na, as the organic matter content of the soil increased due to the addition of compost.

In Egypt when comparing rice straw compos (RSC), water hyacinth compost (WHC) and gypsum for its ameliorating effect on soil salinity, Abdel-Fattah (2012) reported that all treatments, either singly or in combination, showed a pronounced decrease in EC, pH, SAR in addition to exchangeable sodium percentage (ESP) compared to the control. The rice straw compost showed a relatively greater effect on reducing EC, pH, SAR and ESP than the water hyacinth compost, but a combination of either of them with gypsum gave the best results on decreasing soil salinity. In a similar study also conducted in Egypt, Elsharawy et al. (2008) compared the effect of two biological by-products from a citrus manufacturing company with compost and gypsum to improve the clay texture of salt-affected soil. A decrease in soil bulk density, and an increase in available water content and hydraulic properties was reported due to gypsum, byproduct-1, byproduct-2 and the compost applications. In addition it was found that total soluble salts, pH, soluble Na^+ and Cl^-, and SAR values were reduced significantly, and that Ca^{2+} and SO_4^{-2} levels were significantly increased as a result of application of any of the ameliorants as compared to the control treatment. When the compost leachate was added to the irrigation water by means of two different techniques, Panahpour et al. (2011) reported a reduction in soil pH, an increase in both soluble salts and organic matter content, together with an increase in the nutrients P, Zn^{2+}, Fe^{2+}, Cu^{2+} and Mn^{2+}.

Finally, in a study conducted in Egypt over two seasons on sweet basil plants, Abo Kora and Mohsen (2016) investigate the effects of two plant growth promoting rhizobacteria (PGPR) after encapsulating on basil *Ocimum basilicum*,cv. "Grand Vert" plants when were grown with three levels of compost (0, 20, 40 m^3/fed) under conditions of soil salinity. Vegetative growth, essential oil %, essential oil yield and its chemical composition were recorded. Results showed that compost treatments increased total chlorophyll content (a+b), total carbohydrates % and nutrient concentration of P and K^+ in the plant, while it reduced the Na^+, proline and antioxidant activity content of compost treated plants compared to those of the control treatment.

6.5 Salinity ameliorated by addition of beneficial bacterial and fungal species

A well-known practice by farmers to improve soil characteristics and reduce salinity is the addition of beneficial species of bacteria and fungi. This approach has shown to be effective to provide more nutrients to the roots, specially phosphorous and other micronutrients, mostly by the mechanism of lowering the soil pH and making some elements more soluble in the soil solution, thereby increasing their availability to the plant. Fan et al. (2010) investigated the influence of arbuscular mycorrhizal fungi (AMF) on biomass and root morphology of three strawberry cultivars, ‘Kent’, ‘Jewel’ and ‘Saint-Pierce’, that were treated with three levels of NaCl at 0, 30 and 50 mmol.L^{-1} in a greenhouse environment. Results indicated that the presence of AMF significantly changed root morphology and increased root length percentages of medium and course roots, while also increasing shoots and root tissues biomass, the root to shoot ratio (R/S) and specific root length, regardless of cultivar and salinity level. Although salt rates affected the above-mentioned traits negatively, the AMF colonization rates were also reduced linearly and significantly so with increasing salinity levels. It was concluded that cultivars were more responsive to AMF than to salt stress and that the AMF symbiosis highly enhanced salt tolerance of strawberry plants.

Salimpour et al. (2010) studied different treatments in an attempt to enhance phosphorous availability to canola (*Brassica napus* L.) by using P solubilizing and sulphur oxidizing bacteria. Treatments included: a control; a triple super phosphate (TSP) applied at 80 kg.ha^{-1}; rock phosphate (160 kg.ha^{-1}); rock phosphate + organic matter as tea waste applied at 1000 kg.ha^{-1}; rock phosphate + organic matter + P solubilizing bacteria; rock phosphate + element sulphur applied at a rate of 1000 kg.ha^{-1} + *Thiobacillus* sp.; rock phosphate + *Thiobacillus* sp. + organic matter, and finally rock phosphate + elemental sulphur + *Thiobacillus* sp. + organic matter. Production data were collected at the end of the season, and indicated that triple super phosphate at 80 kg.ha^{-1} delivered the highest production in terms of yield and fresh weight of the green components compared to the control treatment at 96% and 92% increase respectively. However, the treatment which entailed the use of rock phosphate in combination with elemental sulphur, *Thiobacillus* sp., and organic matter produced the highest oil percentages. These results thus confirmed that a combination of chemical and biological methods can be effective to create the most favourable environment to enhance the efficiency of natural phosphorous in the soil (rock phosphate).

Samiran et al. (2010) reported two strains *Athrobacter* sp. and *Bacillus* sp., that were isolated from tomato rhizospheres to have the potential to be used as plant growth promoting rhizobacteria (PGPR). This conclusion was reached after screening these species on the base of their phosphorous solubilization strength, their ability to solubilize insoluble phosphate forms, and to promote indole-acetic acid (IAA) production in the plant, and by also evaluating their performance under wide range of temperature, pH and salt stresses.

Anburaj et al. (2010) conducted a study which aimed to understand the role of rhizospheric micro-organisms on plant performance, by comparing plant growth, antioxidant content, as well as pigments and ion concentrations in *Sesuvium potulacastrum*. Plants grown in non-sterilized soils were reported to show more enhanced growth, suppression of antioxidant enzymes, increased chlorophyll and carotenoids content, and a greater accumulation of sodium along with a lowered potassium concentration in the soil than plants grown in sterilized microbe free soils. The micro-organisms that were native and isolated from the soil were *Bacillus cereus*, *Aermonas hydrophila*, *Pseudomonas aeruginosa*, *Corynebacterium xerosis* and *Escherichia coli*.

Mohamed and Gomaa (2011) reported a significant increase in fresh and dry mass of roots and leaves, photosynthetic pigments, proline, total free amino acids, crude protein content, phytohormone content (IAA and GA_3), as well as in concentration of N, P, K^+, Ca^{+2}, Mg^{+2} after inoculation with *Bacillus subtilis*. Furthermore, when *Raphanus sativa* seeds were inoculated with *Bacillus subtilis* and *Pseudomonas fluorescen*a, under NaCl-induced saline conditions, a decreased ABA concentration along with a lowered Na^+ and Cl^- content was reported. The decrease in ABA, as well as Na^+ and Cl^- reduction in response to the activation process is considered part of a mechanism by which alleviation of salinity is achieved.

In a pot experiment, Motlagh et al. (2011) studied the effect of saline irrigation water, mycorrhiza fungi and P fertilizer on the yield and yield components of the common bean (*Phaseolus vulgaris* L.). It was reported that an increase in salinity reduced the number of pods per plant, the number of seeds per pod, the average weight of 100 seeds and the yield in seeds significantly. Increased salinity however also resulted in a significant increase in the proline concentration of saline treated plants. Mycorrhizal fungi treatment had no significant effect on the number of pods, seeds per pod and the weight of 100 seeds when compared to the control plants. The interaction between P and salinity was significant in terms of increased yield of seeds, although at a low salinity stress level, the application of a combination of P fertilizer and mycorrhizal fungi did reduced the salinity effect on the normal yield.

Maziah et al. (2009) reported that the addition of rhizobacteria to a medium supplied with 0.2% NaCl caused an improvement in growth and root biomass of banana plantlets when compared to the saline control of 0.2% NaCl. In addition, an increase in protein, nitrate, soluble nitrogen and chlorophyll contents in plantlets was reported with the addition of rhizobacteria to the saline environment. Maziah et al. (2009) stated that the improvement in growth and biomass accumulation with rhizobacteria was even more significant when boron, nitrogen or carbon were added in the saline medium.

Abo Kora and Mohsen (2016) reported that the two plant growth promoting rhizobacteria (PGPR) *Paenibacillus polymyxa* and *Azospirillum lipoferum* enhanced the traits of growth and essential oil in basil plants compared to plants that were planted in control, saline soils.

6.6 Glycine betaine, an alternative approach for plant adaptation under saline soils

Soil amelioration is not the only option to enhance chances for plant survival under saline conditions. An alternative strategy to acquire internal tolerance to salinity is the addition of specific molecules with the ability to mediate metabolic stress inside the plant. One such a molecule discovered and researched more recently is glycine betaine.

According to Rhodes and Hanson (1993) glycine betaine is considered a quaternary ammonium compound that is found in bacteria, cyanobacteria and algae, in addition to animals and plants of several families. Hanson (1980) stated that glycine betaine also actively accumulate in the leaves of some plants due to saline and drought stress conditions. It is this accumulation of glycine betaine under salinity conditions that may have an effect on plant tolerance to osmotic stress (Styrvold et al., 1986). As not all higher plants are capable of producing or accumulating glycine betaine naturally in their leaves during stress, with tomato being a typical example of such a plant, exogenous application of glycine betaine has been considered a possible control option for various crops. Yang and Lu (2005) hypothesised that exogenous application of glycine betaine to the crops may assist in reducing the negative effect of a range of abiotic stress conditions, including salinity.

Rezaei et al. (2012a) studied the effect of exogenous glycine betaine on the yield of two cultivars of soybean that was cultivated under extreme soil saline conditions where an EC of 11.1 dS.m^{-1} was registered. Glycine betaine was applied around the flowering stage as a foliar spray at 0, 2.5, 5, 7.5 and 10 kg.ha^{-1} respectively. Results showed that glycine betaine accumulation occurred more in young leaves than mature leaves. The number of lateral branches and the number of pods per plants were increased by 33% and 49% for the 10 kg.ha^{-}

^{1} treatment compared to the control treatment. All treatments were reported to significantly increase the weight of one thousand seeds, with the best results obtained with the highest concentration treatment of 10 kg.ha^{-1} that resulted in a 71% increase in weight compared to the control treatment seeds.

Rezaei et al. (2012b) reported on the effect of glycine betaine treatment on tomato grown under drought stress conditions. This study is of interest as drought stress have the same physiological effect on the plant as soil salinity stress. It was reported that the vegetative growth traits of shoot height, root length, leaf number and leaf area increased by 70%, 73%, 187%, 193% respectively for glycine betaine-treated plants at the application of 10 mM glycine betaine with ten days intervals compared to control plants. The physiological characteristics of total shoot fresh weight, total shoot dry weight, relative water content and stress tolerance index increased by 168%, 9%, 72% and 122% respectively for plants where stress was ameliorated by means of glycine betaine at the same concentration of 10mM applied at ten days intervals applications, compared to drought stricken plants without any ameliorating treatment.

For wheat cultivated in Saudi Arabia, Salama et al. (2015) found that salt imposition negative affected the crop by increasing the level of Na^{+} and Cl^{-}, while reducing the Ca^{2+} and K^{+} levels in both shoots and roots. Exogenous application of glycine betaine however was able to alleviate the deleterious effects of salinity on growth and the mineral content, with the greatest efficacy observed at a concentration of 25 mM.

In a study that investigated the antioxidant system and ion accumulation in salinity-exposed safflower seedlings, Alasvandyari et al. (2016) stated that glycine betaine increased seedling resistance to salinity by increasing the levels of catalase (CAT), superoxide dismutase (SOD) enzyme activities and protein content, while simultaneously reducing the activity of peroxidase (POD) inside the seedlings.

Further support for the ameliorating role of glycine betaine in reducing the effect of salinity can be found in a study on vinal seedling by Meloni and Martinez (2009). This study reported salinity to negatively affect dry biomass, to increase Na accumulation and by reducing K accumulation in leaves, thus increasing the Na:K ratio. However, the exogenous application of glycine betaine at a concentration of 8 mM was successful in mitigating a reduction in dry biomass, while reducing Na accumulation and increasing K accumulation in leaves, thus resulting in a lower and closer to a natural Na:K ratio.

6.7 Salinity amelioration by the use of sea weeds extracts

Seaweeds are defined as green, brown and red marine macro-algae. Extracts of brown seaweeds are widely used in horticultural crops, largely for their plant growth-promoting effects and for their ameliorating effect on crop tolerance to abiotic stresses such as salinity. Battacharyya et al. (2015) suggested the addition of seaweed extract as a soil application as a remedy to salinity to be added to the list of possible remedies available to farmers. The performance of seaweed fertilizer to support and increase soybean crop yield was found to be superior to that of conventional manures. Of interest is that dilute seaweed extracts were found to be more effective than concentrated extracts as a 1% seaweed liquid fertilizer, with or without NaCl salt, produced a higher yield, chlorophyll pigment and an improved soil profile compared to the other concentrations evaluated (Ramarajan et al., 2013).

A study by Kasim et al. (2015) conducted on wheat in Egypt found that the seaweed extract of *Sargassumor ulva* antagonized the oxidative damaging effects of drought, not only directly through activating the anti-oxidative enzymes such as catalase, peroxidase and ascorbate, but also through providing essential hormones and micro-nutrients required for growth. In a comparative study, also on wheat in Egypt, Ibrahim et al. (2014) investigated the efficacy of the extracts of *Ulva lactuca* as a 1% pre-planting soaking treatment for seed to combat salinity. Results showed that the activity of superoxide dismutase (SOD) and catalase (CAT) increased with increasing algae extract concentration. It was proposed that the bioactive components in *Ulva lactuca* extracts such as ascorbic acid, betaine, glutathione, and proline could have participated in the release of salinity stress. Kasim et al. (2015) concluded that algal pre-plant soaking can be considered as an effective technique to improve the growth of wheat seedlings under salt stress conditions.

7. Conclusion

The concept of salinity, either referring to the soil or the irrigation water, implicates the presence of undesirable salts in the described medium, that will inevitably result in negatively affecting vegetative and reproductive growth as manifested in a range of physiological and quantitative traits. Salinity is a wide spread phenomenon all over the world, with almost each continent being affected, particularly so in western Asia and parts of the Middle East where salinity remains a constant challenge and threat. In the combat against salinity, a wide range of crops have been screened and evaluated for the effect of soil and water salinity on production in order to predict the potential yield reduction in relation to a known EC.

Banana and tomato are two important international crops that are affected by both salinity of soil and that of irrigation water. Therefore, extensive research has been conducted to report on the effect of salinity on these crops, especially with regard to root biomass reduction, together with growth and yield reduction, but also on the physiological aspects affected by salinity.

Over time farmers in the Middle East region have developed various practices to reduce the effect of salinity; these may include both mechanical approaches or by involving the application of chemical formulations such as soil conditioners, where the latter is considered one of the most effective ways to counteract salinity. Ca, K and N have been identified as mineral elements which can effectively ameliorate the effect of salinity. Other approaches may include the addition of compost, sulphuric acid, seaweed extract or specialized organic molecules such as glycine betaine to soil. The inclusion of these components in the correct formulation can assist the plant to adjust saline conditions and produce yield comparable to plants grown under non-saline conditions.

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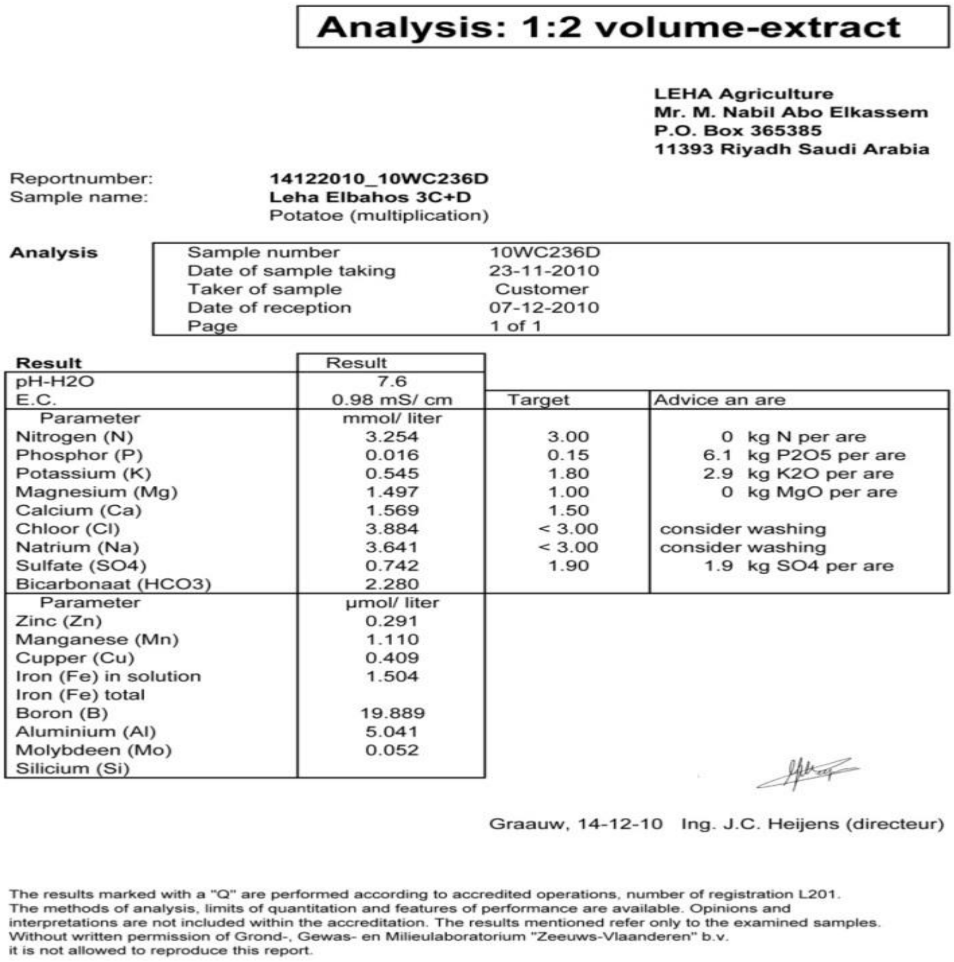

Analysis: 1:2 volume-extract

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P.O. Box 365385
11393 Riyadh Saudi Arabia

Reportnumber: **14122010_10WC236D**
Sample name: **Leha Elbahos 3C+D**
Potatoe (multiplication)

Analysis

Sample number	10WC236D
Date of sample taking	23-11-2010
Taker of sample	Customer
Date of reception	07-12-2010
Page	1 of 1

Result	Result	Target	Advice an are
pH-H2O	7.6		
E.C.	0.98 mS/ cm		
Parameter	mmol/ liter		
Nitrogen (N)	3.254	3.00	0 kg N per are
Phosphor (P)	0.016	0.15	6.1 kg P2O5 per are
Potassium (K)	0.545	1.80	2.9 kg K2O per are
Magnesium (Mg)	1.497	1.00	0 kg MgO per are
Calcium (Ca)	1.569	1.50	
Chloor (Cl)	3.884	< 3.00	consider washing
Natrium (Na)	3.641	< 3.00	consider washing
Sulfate (SO4)	0.742	1.90	1.9 kg SO4 per are
Bicarbonaat (HCO3)	2.280		
Parameter	µmol/ liter		
Zinc (Zn)	0.291		
Manganese (Mn)	1.110		
Cupper (Cu)	0.409		
Iron (Fe) in solution	1.504		
Iron (Fe) total			
Boron (B)	19.889		
Aluminium (Al)	5.041		
Molybdeen (Mo)	0.052		
Silicium (Si)			

Graauw, 14-12-10 Ing. J.C. Heijens (directeur)

The results marked with a "Q" are performed according to accredited operations, number of registration L201.
The methods of analysis, limits of quantitation and features of performance are available. Opinions and interpretations are not included within the accreditation. The results mentioned refer only to the examined samples.
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Paper 2: Variation in Salinity Tolerance of Five Determinate Tomato Cultivars Commercially Grown in the Jordan Valley

ABSTRACT

Salinity, a major limiting factor affecting commercial tomato production in the Jordan Valley, was studied. Trials were carried out on two planting dates that commenced during October 2012 (winter planting) and August 2013(summer planting) respectively. Each planting included the five widely planted tomato cultivars: 'Majd', 'Alam' 'Asalah' 'Ayah' and 'Bahjah'. Cultivars were exposed to five different levels of salinity, as induced by the addition of NaCl to the fertigation tank, with NaCl concentrations increasing progressively from 1, 2, 3 and 4 to 5 g.L^{-1}. Growth parameters measured weekly included plant height and leaf number, while fresh root - and shoot weight for both plantings, along with dry root - and shoot weight for the August 2013 planting, was determined at harvest. Results showed that increased salinity was associated with reduced plant performance for these parameters. The summer planting, with the extra heat stress effect, showed more variation between cultivars. Yet, in terms of salt tolerance, 'Ayah' was observed in general to be the most tolerant and vigorous among the cultivars, with 'Bahjah' in general showing less tolerance and vigour than the other cultivars evaluated. In the case of the winter planting, differences between cultivars were not significant, in spite of 'Ayah' performing the best. However, in the summer planting, 'Ayah' performed significantly better than all other cultivars.

ADDITIONAL INDEX WORDS

Abiotic stress, dry weights, fresh weights, leaf number development over time, NaCl, plant height development over time, salinity.

Introduction

Salinity is considered to be one of the most severe abiotic stress factors limiting productivity of crops world-wide (Ghassemi et al., 1995). Choosing unsuitable irrigation methods, in addition to either using poor water quality or having insufficient or a total lack of drainage, poor land- and crop management are amongst the main factors inducing severe changes in the overall level of soil salinity experienced globally (Ammari et al., 2013). Seventeen percent of the cultivation area worldwide are considered to be under irrigation, with irrigated agriculture contributing well over 30% of the total agricultural production. It is estimated that up to 50% of all irrigated lands may already be salt-affected (Hillel, 2000). In the Middle East, throughout Jordan, Palestine and Israel, where soils are saline and water availability is very low, salinity is considered the first and most important factor limiting optimum water utilization and crop production (Flowers, 1999; Szabolcs, 1992; Vengosh and Rosenthal, 1994).

The Jordan Valley, which is mostly located to the north of the Dead Sea, is an important agricultural region with a cultivated area of about 35 000 ha (Abu Aisha, 2001). More than 60% of vegetable production of Jordan is located in the Jordan Valley. Great variation in soil physical classification, annual rainfall, crop growth- and irrigation systems exists throughout the Jordan Valley. Yet, a common factor throughout this region is an increase in salinity of irrigated soils due to the absence of natural floods, the high evaporation and insufficient rainfall in this area, as these factors are collectively considered critical for leaching of salts from soil to prevent their accumulation (Ammari et al., 2013).

On a global scale, with a total production of 152.9 million tons and a value $74.1 billion, tomato (*Solanum lycopersicum* L.) is the second most important vegetable crop grown, following potato (FAOSTAT database, 2009). Also, as most commercial tomato cultivars are classified as moderately salt tolerant (Maas, 1986), tomato was generally recommended as appropriate for saline land recovery (Reina-Sanchez et al., 2005), making this crop apparently ideally suited for production in the Jordan Valley. As a result, tomato is currently considered the leading vegetable crop grown for both local consumption and export in the Jordan Valley, representing 27.5% of the total vegetables produced. Tomato is estimated to comprise 3% of the total cultivated area, in 2010, contributing 371 257 metric tons annually (ILO report, 2014). These production figures resulted in Jordan to be listed among the top ten tomato exporting countries worldwide. In 2012, following a rapid increase from the 7 656 ha (2002) to 12 345 ha (green house and open field production), tomato production represented the highest vegetable component, being 43% of the total vegetable production. Cucumber production was next highest at 9.2%, whilst potato production is the third most produced vegetative crop at 8.3% (ILO report, 2014).

The extent to which a crop responds to salinity is largely influenced by its genetic potential. Foolad and Lin (1998) stated that large genetic variation in tolerance to salinity exists among different tomato genotypes. Hartz (1990) mentioned in his review that commercial varieties of tomato, that are sensitive to even moderate levels of salinity (2.5 $dS.m^{-1}$), did in general not show a reduction in yield. In a study based in Iran, Kaveh et al. (2011) reported the germination percentage of different lines of tomato to decrease when exposed to four increasing levels of salinity of 0.5, 2.5, 5 and 10 $ds \cdot m^{-1}$ respectively. In a Tunisian study by Kahlaoui et al. (2011), three tomato cultivars were negatively affected by saline water as noted by reductions in leaf area, petiole size and stem and root weight. Interestingly, the fruit were less affected. Najla et al. (2009) reported that varying electrical conductivity of the fertigation solutions of 4, 7, 10 and 13 dS.m^{-1} respectively, resulted in a reduction in leaf area dimensions as well as a modification in growth rate and duration of tomato. Longer growth durations at high salinity levels were recorded, while the internodes were distinctly shortened by salinity, leading to a reduced height and diameter of the affected plants. In support of the finding of this study, a similar reduction in leaf dry weight was reported by Ismail et al. (1994). The photosynthetic rate was not affected, however, even though stomatal conductance and leaf water potential were reduced in the plants exposed to high levels of salinity.

When brackish water was used in a greenhouse study (Del Amor et al., 2001), salinity was found to affect tomatoes significantly, by reducing the size and number of marketable fruit. Leaf and fruit calcium (Ca) and potassium (K) concentrations were also significantly reduced with increasing salinity, whilst fruit eating quality was enhanced due to an increased total soluble solids and sugar content. Similarly, Abu-Khadejeh et al. (2012) reported a negative response in fresh weight, dry weight and plant height of tomato when conducting a hydroponic study exposing plants to various NaCl and $CaCl_2$ solution concentrations in Jordan. In this study, it was also reported that sodium (Na^+**)**, chlorine (Cl^-) and Ca^{2+} content increased, along with proline concentrations, whilst K^+ accumulation decreased in both evaluated cultivars with an increase in salinity. Salinity tolerance as a trait in tomato is thus of key importance in Mediterranean regions, where plants are often subjected to high levels of soil salinity due to elevated soluble salts in irrigation water in combination with fertilizers (Al-Karaki, 2000).

In this study, five determinate tomato cultivars namely ‘Alam’, ‘Majd’, ‘Asalah’, ‘Ayah’ and ‘Bahjah’, were selected on the basis of their high productivity, preferred fruit size for existing markets, extended shelf life, and their tolerance and resistance to biotic stress, such as nematodes and the pathogens *Verticilium*, *Fusarium* (Races, 0, 1, and 2), as well as some viral diseases like TYLCV (Tomato Yellow Leaf Virus). However, no scientific data is available on the salinity tolerance of these commonly produced varieties of the Jordan Valley and Highlands, where the soils are classified as moderate to severely saline. The aim of this study was thus to evaluate these five most widely planted cultivars for differences in tolerance to NaCl salinity stress, in the context of both a summer and winter planting. The outcome of this study will assist to provide a greater understanding of the impact of salinity on tomato growth and development by comparing two production season. In addition, the results of this study will provide guidance when making recommendations regarding cultivars that are best suited for the wide range of production conditions associated with the Jordan Valley.

Materials and Methods

Plant material. Five determinate tomato (*Solanum lycopersicum*) cultivars, grown commercially in the Jordan Valley, were chosen for this study namely: 'Majd' F1 (Hizera Technology seeds, Israel), 'Alam' F1 (Agri Semen, USA), 'Asalah' F1 (Eastern Company, USA), 'Ayah' F1 (Clause, USA) and 'Bahjah' F1 (Yuksel seeds, Turkey). Seeds of these cultivars, sourced from their local distributors, were planted in planting trays in a medium comprising of 50% peat moss and 50% coco peat. The young plants were kept in the Modern Technical Nursery, South Shoonah (GPS coordinates 31 52` 16.85"N, 35 37` 21.35"S) for a hardening period of four weeks, before being transplanted separately into pots, at the four to five true leaf stage. Both a winter and summer planting was conducted, in October 2012 and August 2013 respectively, where each planting consisted of 100 plants per cultivar (500 potted plants in total). At transplant, seedlings were transferred from the planting trays into pots (16 x16 cm) filled with saline, silty-clay soil that was obtained and considered representative of that from the Jordan valley.

Abiotic conditions. The winter planting was initiated on 30 October 2012 and was terminated six weeks later, on 15 December. The summer planting commenced on 12 July 2013, with harvesting scheduled for 22 August 2013, six weeks later. In winter, temperatures at the cultivation site ranged from 14-20˚C during the daylight hours and between 12-16 ˚C at night. In summer, temperatures varied between 40-46˚C during the daylight hours, with a typical range being 30-36 ˚C at night. Relative humidity (% RH) varied from 35-75%, depending on the season. No rainfall was recorded for summer planting and negligible amount of rain not recorded took place on the winter planting.

Pots were placed under a tunnel frame covered with 60% black shade netting for the entire duration of the trial. In winter, the tunnel received additional covering with plastic to prevent any rain from entering. No rain occurred during the summer months during the trial period. Soil analysis was done by the Arab Centre for Engineering Studies LTD (www.aces-int.com) (Table 1).

Nutrition. The pots of both plantings were fertigated on a daily basis, from each of five solutions in 1000L capacity tanks. Each tank contained the same fertilizer blend (which excluded Ca to prevent any precipitation), but differed in NaCl concentration, to include 1,2, 3, 4 and 5 g.L^{-1} . The fertilizer blend selected represented the formulation routinely used by tomato producers of the Jordan Valley and neighbouring countries and is considered to optimize all mineral nutrition aspects of tomato production this region. The nutrient ratio was as follows: N: 1.7; P: 0.38; K: 2.15; Ca: 0.75; Mg: 0.45; S: 0.6; in addition to trace elements: at 0.01, that consisted of all the essential trace elements namely Fe, Zn, Mn, Cu, B and Mo.

Each of the five tanks contained 560 g of potassium nitrate (KNO_3), 137 g of mono-ammonium phosphate (MAP), 44.5 g of ammonium nitrate (NH_4NO_3), 246 g of magnesium sulphate ($MgSO_4$), 0.5g of copper (chelated in EDTA), 8g of iron (chelated in EDDHA), 1.2g of manganese (chelated in EDTA), 1.2g of zinc (chelated in EDTA), 1 g of boric acid and 0.05 g of sodium molybdate (Na_2MoO_4). The blend in each tank was agitated with a suitable mixer weekly to ensure homogeneity of the solution (Table 2). An additional 1000 L tank containing 437.5 g of calcium nitrate ($CaNO_3$) was used to supply Ca in conjunction with the nutrient solution from the fertilizer-blend tanks (Table 2).

Daily fertigation was provided from the blend-tanks, except for once a week (Fridays), when only $CaNO_3$ was applied. Fertigation rates were set to ensure 20% drainage per pot during the first 30 minutes of fertigation. For the winter planting, an initial 1000 ml per pot was applied during the first week, where after the delivery was reduced to 600 ml from 10 November onwards, until the termination of the trial. For the summer planting, an initial fertigation rate of 1000 ml per pot was scheduled, where after it was reduced from 25 July to 800 ml per pot. This fertigation rate was based on weekly observations of the drainage quantity as affected by environmental conditions such as temperature and humidity. Fertigation was carried out daily in the morning between 05.00 and 07.00 when conditions were cool. The pH and electrical conductivity (EC) of the solution in each tank were monitored weekly during the first three to four weeks following trial commencement. Values for pH ranged from 6.1 to 6.6, whilst the EC ranged from 2.5 to 5.2, depending on the tank formulation. Soil pH varied between 6 and 6.8. Pesticide or fungicide applications were not required, mainly due to the netting cover which prevented pest attacks, whilst the prevalent dry conditions did not favour pathogen infections.

Data collection. Measurements of plant height (mm) and leaf number for both plantings were recorded on a weekly basis. Fresh shoot- and root weight (g) were recorded at the time of trial termination. In summer, dry shoot- and root weights (g) were also recorded. Unfortunately, dry weights could not be measured in the winter planting, as continuous rain did not permit the process of sun drying.

Experimental design. A Randomized Complete Block Design (RCBD) was used, with 20 single plant replicates, resulting in 25 treatment combinations, with variety and salt concentration as main factors. Each cultivar was treated with five salt concentrations in each replicate (n=20). The data were subjected to analysis of variance and where appropriate the

Bonferroni's LSD post hoc mean separation test at the 5% significant level was carried out using Enterprise guide, STATISTICA 13.2.

Results and Discussion

Winter planting - Plant height over the growth season (2012). The weekly increase in plant height over the growing season did not show any interaction between salt concentration, cultivar and time (Fig. 1). Similarly, no interaction between salt concentration and cultivar was evident, (Fig. 1). However, an interaction between time and cultivar, as well as between time and salt concentration was observed, implicating that the various cultivars were affected differently by salinity over time, as well as that plants exposed to the different salt concentrations, did not elongate in the same manner over time (Fig. 1). Plant height was progressively affected by increasing salinity concentrations over the growth season, so that the tallest plants were consistently associated with the lowest concentration. Plants that were grown under the highest salt concentration regime was thus most severely affected. A reduction in plant height development due to an increase in NaCl concentration was similarly reported by Mustard and Renault (2006) on red-osier dogwood (*Cornus sericea* L.) and also on pepper (*Capsicum annuum*) by Houimli et al. (2008), in Tunisia.

The distinct differences in the response of the various cultivars to salinity, as observed over the growth season, implicate important differences in salt tolerance between the cultivars evaluated (Fig. 1B). Cultivars 'Ayah', 'Majd' and 'Alam' delivered comparative increased plant height weekly increments over the production period and was significantly higher throughout the evaluation period than 'Asalah' and 'Bahjah'. 'Bahjah' produced the lowest plant height increase of all cultivars throughout the evaluation period. This result concur with Houimli et al. (2008) in a study conducted in Tunisia, where peppers (*C. annuum*) were irrigated with water to which 0.4g.L^{-1} NaCl was added. The results showed that vegetative growth was significant decreased by salinity, but also that shoot growth in particular, was more severely affected than root growth.

Winter Planting - Plant height at harvest (2012). No interaction was recorded between salt concentration and cultivar for final plant height at harvest (Table 3). However, both salt concentration and cultivar significantly affected the final plant height at the termination of the trial. Plant height were clearly stunted by increasing salinity, as salt concentration at the lower salinity range of 1 , 2 and 3 g.L^{-1} scored the highest final plant height, while the lowest plant height was recorded for plants exposed to the highest salt concentration of 5g.L^{-1} (Table 3).

Cultivars ‘Ayah’, ‘Alam’ and ‘Majd’ had the highest final plant height, whilst ‘Bahjah’ was second highest, but with no significant difference from ‘Alam’ and ‘Asalah’ (Table 3). Similarly, a reduction in plant height due to an increase in NaCl concentration was also reported by Mustard and Renault (2006) on red-osier dogwood (*Cornus sericea* L.), where seedlings treated with 50 mmol·L^{-1} NaCl for 32 days had significantly lower shoot dry mass and shoot heights than untreated seedlings.

Summer Planting - Plant height over the growth season (2013). As in the winter planting, no interaction between salt concentration, cultivar and time was reported in the summer planting for the weekly increase in plant height over the growing season (Fig. 2). Also, no interaction between salt concentration and cultivar was found (Fig. 2). However, an interaction between time and cultivar, as well as between time and salt concentration, was observed (Fig. 2). As the salt concentration increased, the plant height weekly development was shown to be differentially affected, similar to observations made for the winter planting. Increasing salt concentrations progressively reduced plant height, even more so than for the winter planting (Fig. 1), so that plants exposed to the highest salt concentration also displayed the shortest plant height, throughout the season (Fig. 2A). Plant heights obtained throughout the season showed that plants exposed to the various salt concentrations differed significantly and consistently from each other with respect to this parameter (Fig. 2A).

The distinct differences in the response of the various cultivars to salt concentration as observed over the growth season indicate important differences in salt tolerance between the cultivars evaluated (Fig. 2B). Cultivar ‘Ayah’ performed well under conditions of salinity, especially towards the later part of the growing season. ‘Majd’, ‘Alam’ and ‘Asalah’ appeared to be equally and more affected by salinity then ‘Ayah’, but not to the extend by which ‘Bahjah’ was affected – showing the lowest plant height at harvest (Fig. 2B). A clear difference in tolerance to salinity is thus evident between the various cultivars throughout the season, yet at harvest, only ‘Ayah’ differed significantly from ‘Bahjah’.

Summer Planting - Plant height at termination (2013). No interaction was recorded between salt concentration and cultivar for final plant height at harvest (Table 4). As in the winter plantings, increasing salt concentration progressively and significantly reduced the final plant height mean (Table 3), where the tallest plants were recorded in the lower salt concentration treatment of 1g.L^{-1} (21.87 cm), while the shortest plants resorted with the top salt concentration treatment of 5 g.L^{-1} (14.43 cm) (Table 3). Salt concentration treatments with 4 and 5 g.L^{-1} did not differ significantly between each other, while all the other salt concentration treatments differed significantly among each other (Table 3). Cultivar ‘Ayah’ produced significantly taller plants at a final plant height of 20.74 cm, whereas the plant height recorded from all the other cultivars did not differ significantly from each other (Table 3).

The summer planting was planted 40 days before the normal season planting started, which exposed plants to extreme temperatures conditions, often above 40 °C. When comparing final plant heights of the various cultivars between winter and summer plantings, it is evident that heat stress, when occurring in combination with salinity, provides an association that is severely detrimental to plant growth, and in particular plant height, in this instance. It was however, under these harsh conditions, that cultivar 'Ayah' differentiated itself as a more saline tolerant and vigorous cultivar. This finding prompts further research to determine the impact of other abiotic stress conditions such as induced drought conditions, on above mentioned cultivars. Also, the mechanism(s) which permits 'Ayah' to excel under adverse environmental conditions compared to the other cultivars, may offer solutions to producing tomatoes in future under extreme environmental conditions. However, under more mild conditions such as a winter planting, cultivars such as 'Alam', 'Majd', 'Asalah' and possibly 'Bahjah' are still considered suitable, provided that a threshold salinity concentration is not exceeded. Our results suggested that this threshold may exist below an additional 3g.L^{-1} NaCl, that may be added to the existing soil.

Winter planting - Plant leaf number as monitored over the growth season (2012). The weekly increase in plant leaf number over the growing season did not show any interaction between salt concentration, cultivar and time (Fig. 3). Similarly, no interaction between salt concentration and cultivar was found (Fig. 3). However, there was an interaction between time and cultivar, as well as between time and salt concentration reported (Fig. 3). Increasing salt concentration negatively affected the increase in plant leaf number as monitored on a weekly basis. (Fig. 3A). Plants that were cultivated with only additional 1g.L^{-1} salt, had the highest plant leaf number, and this value differed significantly between the salt concentration treatments (Fig. 3A).

Cultivars 'Ayah', 'Majd' and 'Alam', and initially 'Asalah', showed a comparative number of leaves when monitored on a weekly basis (Fig. 3B). However, toward the later part of the production season, 'Asalah' produced a lower number of leaves than its counterparts. However, throughout the monitoring period, 'Bahjah' produced significantly less leaves than any of the other cultivars (Fig. 3B).

Winter Planting – Plant leaf number at harvest (2012). No interaction was recorded between salt concentration and cultivar for final leaf number counted at harvest (Table 4). The plants with the highest leaf number were recorded in the lower salt concentration treatment of

1g.L^{-1} (9.52), while the lowest leaf number plants resorted with the top salt concentration treatment of 5 g.L^{-1} (7.37) (Table 4). Significant difference did exist between salt concentrations (Table 4). In a future trial, it would be useful also to not only document number of leaves produced on exposure to salinity, but also to record leaf area at harvest, or leaf area per leaf weight, to provide further information on the interactions of the anatomy of a crop with its physiology under conditions of environmental stress.

For this trial, cultivar 'Ayah', which scored the highest number of leaves (8.63), did not have significantly more leaves than either 'Majd' or 'Alam'. However, lower number of leaves at harvest was recorded for both 'Asalah' and 'Bahjah' compared to 'Ayah'. More leaves and/or leaf area per plant is highly beneficial under conditions of stress as it may facilitate photosynthesis under conditions, already limiting for this life sustaining process.

Summer Planting – Plant leaf number monitored over the growth season (2013). As in the winter planting, no interaction between salt concentration, cultivar and time was recorded for the summer planting with respect to plant leaf number (Fig. 4). Also, no interaction between salt concentration and cultivar was found (Fig. 4). However, an interaction between time and cultivar, as well as between time and salt concentration was concluded (Fig. 4). An increase in salinity significantly reduced the increase in leaf number when monitored on a weekly basis, similar to the trend noticed in the winter planting. Plants exposed to the highest salt concentration consistently displayed the shortest plant height (Fig. 4A), whilst plants that was grown under the lowest salt concentration (1g.L^{-1}) the highest (Fig. 4A). It is evident from the data that, in the summer planting, leaf formation and/or development, especially at the higher salt concentrations, were severely impaired later in the season, when the effect of the high temperatures and its assumed associated with physiological water stress clearly impacted greatly on the ability of plants to unfold more leaves over time.

'Ayah' produced significantly more leaves than all other cultivars, particularly towards the end of the growing season. This observation provides evidence of 'Ayah' being a particularly vigorously cultivar, with the ability to tolerate salinity conditions, particularly in the presence of other stress factors, such as high temperatures or water stress. Although 'Bahjah' were severely affected by salinity, especially towards the end of the season, when it scored a lowest number of leaves (4.3), yet this did not differ significantly from all the other cultivars, except for 'Ayah'.

Summer Planting - Plant leaf number at harvest (2013). No interaction was recorded between salt concentration and cultivar when considering final leaf number at harvest (Table 4). Increasing salinity consistently decreased the final number of leaves at harvest

(Table 5). The lowest salt concentration at 1 g.L^{-1} produced plants with the highest final plant leaf number mean of 7.49, while reversely, the lowest leaf number of 5.4 per plant was recorded for plants grown under added salinity of 5 g.L^{-1} (Table 4). When Quados (2011), in a trial on *Vicia faba,* exposed plants to NaCl at concentrations of 0, 60, 120 and 240 mM, a decrease in the number of leaves was noted with increased salt concentration, but the trend was not significant, testifying again, as noted in our winter planting, that leaf number as a growth trait can be fairly unresponsive to salinity. However, when the added stress of extreme temperatures interacted with salinity in the summer planting, the role of cultivar was non-significant, but salt concentration was the main driver for difference in leaf number obtained.

At harvest, for the summer planting, all cultivars produced less leaves than in the winter planting, but the number of leaves produced per all cultivar except for 'Ayah', did not differ significantly from each other at the 5% confidence level. 'Ayah' produced the highest final leaf number at harvest and differed significantly from all other cultivars (Table 4). Yet, in another study on tomato by Azarmi et al. (2010), a significant decrease of both plant height and leaf number of hydroponic grown tomato plants were reported when plants were grown under different salinity levels with EC's of 2.5, 3, 4, 5 and 6 dS.m^{-1}, respectively. A significant decrease in fresh fruit weight and yield, which was not recorded in our study, was also reported by Azarmi et al. (2010) with increasing salt concentrations.

In general, unlike plant height, leaf number was less affected in the summer planting compared to the winter planting. In the winter planting, cultivar responses to salinity were the main drivers of changes recorded in leaf number, whilst in the summer planting, the level of salinity, as an additional stress, determined which treatment produced more or less leaves. Thus, when growing tomato under severe summer conditions, as was the case in this study, it is important to selected moderate saline soils, as a vigorous cultivar may not be sufficient resilient to produce sufficient leaves to effectively overcome stress condition.

Fresh shoot weight. No interaction for fresh shoot weight at harvest was found between the main factors of salt concentration and cultivar, in both summer and winter plantings (Figs. 5, 6). For both plantings, an increasing salt concentration had a significant, detrimental effect on the fresh shoot weight at harvest, where a clear decline in final fresh shoot weight was observed with increasing salt concentration. In the winter planting, for the parameter fresh shoot weight, salinity as induced by 1 g.L^{-1} produced the best results where shoot weight of 84.65g was significantly higher than that of any other treatment (Fig. 5). Shoot fresh weight at salt concentrations of 2 g.L^{-1} at 71.59 g and 3 g.L^{-1} at 66.9 g however, did not differ significantly from one another, nor did shoot fresh weight at 4 g.L^{-1} (51.50 g) and 5 g.L^{-}

^{1} (45.35 g) differ significantly from each other. Similar results were reported by Beltagi et al. (2006) on common beans, where fresh shoot length and weight decreased consistently with an increase in NaCl concentration, from 1 to 2 g.L^{-1} and finally to 3 g.L^{-1}, when compared to the control in which the NaCl was kept at 0 g.L^{-1}. A declining trend in shoot length, leaf area, root fresh weight and dry shoot and root weights was also reported with increasing salinity (Beltagie et al., 2006).

In the summer planting, shoot fresh weight were not impacted differently by 1 g.L^{-1} (29.62 g) compared to 2 g.L^{-1} (27.69 g), whereas higher salt concentrations of 3g.L^{-1} (19.69 g) and that of 4g.L^{-1} (16.05 g) reduced fresh shoot weight significantly compared to the lower concentrations. These last mentioned intermediate concentrations was however not as detrimental as the highest salt concentration at 5 g.L^{-1}, which recorded the lowest fresh shoot weight for this planting (9.69 g) (Fig. 6).

When comparing the summer and winter planting, much lower fresh shoot weight were obtained in summer compared to winter. The additional stresses associated with a severe summer impacted particularly negatively on the plants exposed to the highest concentration of salinity at 5 g.L^{-1}, as in the summer planting shoot weigh differed significant from all other treatments, whereas in the winter planting, it was still comparable to the 4 g.L^{-1} treatment, where four times as much fresh weight was produced than could be obtained in the summer planting.

In the winter planting, cultivars ‘Ayah’, ‘Alam, ‘Majd’ and ‘Bahjah’ scored equally with respect to fresh shoot weight at harvest (Fig. 5B). However, ‘Asalah’ produced significantly lower fresh shoot weight compared to all other cultivars. In the summer planting, this trend was not repeated, as ‘Ayah’ produced significantly higher fresh shoot weight compared to the other cultivars, which did not differ from each other (Fig. 6B). In general, all the cultivars obtained much higher fresh shoot weight in the winter planting than in the summer planting, testifying of the extreme and harsh conditions that typical prevail in summer for the Jordan valley. Results indicate that, with regard to above-ground biomass production as was recorded in this study as fresh shoot weight, ‘Ayah’ proved to be far superior to all other cultivars when produced in summer planting, whilst all cultivars were found suitable for the winter planting, except for ‘Asalah’ which produced significant less biomass.

Fresh root weight. Similar to the finding regarding fresh shoot weight, no interaction was reported for fresh root weight between salt concentration and cultivar as main factors, in both winter and summer plantings (Figs. 7, 8). When considering increasing salt concentration, a clear declining trend in the fresh root weight was observed, in both plantings. In the winter planting plants treated with the relative low salt concentrations of 1 g.L^{-1} and 2 g.L^{-1} produced comparative fresh root weights (Fig. 7A). For the intermediate and higher salt concentrations of 3 g.L^{-1} and above, root weight was significantly reduced, especially compared to the lowest salt concentration of 1 g.L^{-1}. The highest salt concentration of 5 g.L^{-1} particularly reduced fresh root weight, compared to the roots of plants that was exposed to the range of 1 to 3 g.L^{-1}, although it did not differ from roots of plants treated with salt at 4 g.L^{-1}.

In the summer planting, the increasing salt concentrations consistently reduced fresh root weight, so that the highest salt concentration at 5 g.L^{-1} detrimentally affected fresh root weight in comparison to plants treated with the remaining salt concentration range (Fig. 8A). The lowest two salt concentration 1g.L^{-1} and 2g.L^{-1} affected fresh root weight production similarly, whereas the mid-range of salt concentrations at 3 and 4 g.L^{-1} affected root weight production in a comparable manner. A reduction in root dry weight with increasing salinity was also reported by Jamil et al. (2005), on a range of crops which included cauliflower, cabbage and canola. In this study, three different treatments with increasing NaCl concentration that ranged from 4.7 to 9.4, or with EC values and even as high as 14.1 dS.m^{-1}, were compared to a control. Results showed that root growth was more affected that shoot growth. In addition, a significant negative association between the salt concentration and the final germination percentage and germination rate, in addition to a reduction in root- and shoot lengths and fresh root-, shoot and plant weights was reported.

In the winter planting, cultivar ‘Alam’ scored the highest fresh root weight at 14.2 g, which did not differ significantly from ‘Ayah’ or ‘Bahjah’, but was significantly differently from ‘Majd’ and ‘Asalah’ (Fig. 7). For fresh root weight, ‘Asalah’ reported the lowest score of 8.72g, which differed significantly from all the other treatments (Fig. 7B). Alternatively, in the summer planting, cultivar ‘Ayah’ scored the highest fresh root weight (5.04g), which was significantly higher than all other cultivars (Fig. 8B). For this planting, ‘Bahjah’, ‘Majd’ and ‘Asalah’ collectively produced the lowest level of fresh root weight (Fig. 8B). As was reported for the fresh shoot weight, fresh root weight production was severely reduced by the harsh summer in general and produced far less root weight for all cultivars than recorded for the winter planting. These results again indicate that ‘Ayah’ have the ability to cope under harsh summer conditions, in this case with regard to root production, in the presence of salinity. Root production for ‘Asalah’ in a winter planting and for ‘Bahjah’ in summer was impeded compared to other cultivars, with stunted root growth being identified as a possible weakness of these cultivars to sustain production under conditions of high stress.

Dry weights for summer planting (2013). Dry mass is considered a more reliable measure of biomass than fresh mass, as the former excludes the fluctuating water concentrations in the biological material. Dry weight as a parameter, if available, is useful as it provides confirmation of trends that was observed with fresh shoot and root weights. Furthermore, clear relationship between dry biomass and productivity in many crops are often researched as is seen in studies by Marcelis (1993) on cucumber, Lins et al. (2016) on watermelon and Patane and Saita (2015), on open field processing tomato.

Shoot dry weight. No interaction emerged for dry shoot weight between the salt concentration and cultivar as main factors in either the winter or summer planting (Figs. 9, 10). Increasing salt concentration had a definite and significant, detrimental effect on the dry shoot weight, where all the respective salt concentrations produced consecutively, significantly lower dry shoot weight with increasing salt concentration (Fig. 9A).

‘Ayah’ obtained the highest dry shoot weight (3.63 g), but did not differ significantly from the dry shoot weight reported for cultivars ‘Bahjah’ and ‘Asalah’, but was significantly higher than that reported for ‘Alam’ and ‘Majd’, which showed the lowest dry shoot weight of 3.15 g and 3.1 g respectively (Fig. 9B). Comparing dry shoot weight with fresh shoot weight, ‘Ayah’ consistently emerged as the cultivar with the highest biomass, which signals an ability to be most tolerant to saline conditions, based on its known vigorous growth traits. When considering plant dry shoot weight, ‘Bahjah’ and ‘Asalah’ perform better in this regard compared to ‘Majd’ and ‘Alam’, indicating the fresh shoot weight might have retained more moisture than other cultivars, which was now eliminated with the drying process. These cultivars may thus be more suitable for production under saline conditions than was estimated by means of the fresh shoot weight parameter.

A study on rice in Sri Lanka by Puvanetha and Mahindran (2017) report a decrease in the dry shoot and root weights when plants were cultivated in a saline soils in compare to controls. To the contrary, results were published by Singh et al. (2012) on tomato production, where sixteen genotypes were evaluated against two NaCl concentrations, namely 1% and 3% NaCl within a Hoagland solution and a control, it was reported that a moderate increase in salt concentration increased both the shoot and root dry weight. An explanation for this apparent discrepancy may either be the resilience of the respective crops, or in the EC values, which was recorded at 6.6 dSm^{-1}, whilst the three concentrations of NaCl for the tomato study ranged from 0.18, 2.5, and 4.5 dSm^{-1} respectively.

Dry root weight. No interaction between the main factors of salt concentration and cultivar was obtained in the summer planting for the parameter dry root weight (Fig. 10).

Increasing salt concentration resulted in a significant decrease in dry root weight, especially in the lower salt ranges of 1 to 3 g.L^{-1}, where significant differences were achieved with each consecutive increase in salt concentration (Fig. 10A). However, for the higher salt concentrations, the severity of the impact of salinity on root weight were comparable (Fig. 10A).

The highest mean dry root weight was recorded in 'Ayah' (0.83g), which differed significantly from all the other cultivars, whilst the remainder of the cultivars did not differ significantly from one another (Fig. 10B). This observation where 'Ayah' was most successful to accumulate root biomass, is comparable to the results reported on the fresh root weights, where again 'Ayah' produced the most fresh root weight, which differed significantly from all other cultivars (Fig. 8B).

Conclusion

Results from this study conclude that salinity impact negatively on tomato growth and development. Even though tomato may be considered to be tolerant to salinity, this may only be true to a limited extend, after which when this limit is exceeded, an increase in salinity level will adversely affect vegetative growth traits that will impact negatively on production.

Significant salt tolerance differences were observed between cultivars included in the study. 'Ayah' was identified as the most promising cultivar for Jordan, with the most vigorous growth and with significantly higher salinity tolerance than the other cultivars. 'Alam' and 'Majd' was mostly rated to intermediately tolerant to salinity, whilst 'Asalah' and 'Bahjah' appear to least suitable for production under severely saline conditions, especially during extreme harsh summer conditions. The effect of growing season was not quantified *per se*, but observations indicated a pronounced additional effect of summer on salinity tolerance and this should be recorded in more detail in future trials. As fruit quality, both in terms of size and taste, is most important in addition to yield, it is recommended that future studies on these cultivars should extend the data collection until harvest to also include production numbers as well assess fruit quality of promising tomato cultivars for production under saline conditions.

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Table 1. The physical and chemical properties of native Jordan Valley soil samples as used as planting medium in a trial which assessed differences in the tolerance of five tomato cultivars, namely, ‘Alam’, ‘Majd’, ‘Asalah’, ‘Ayah’ and ‘Bahjah’ to various levels of salinity.

Potting soil Characteristic	pH[w]	EC[x]	%N	P (mg.L^{-1} [v])	K (mg.L^{-1} [v])	% $CaCO_3$	Exch. Ca[y]	Na % [z]	Cl (mg.L^{-1} [v])
	7.9	2.3	0.3	17.7	219. 5	30	0.04	6.1	110

[v] mg.L^{-1} = parts per million (ppm)
[w]paste extract;
[x]electrical conductivity in dS.m^{-1}, paste extract;
[y]meq.100g^{-1};
[z]ESP % (Exchangeable sodium percentage)

Table 2. The composition of the blend of the fertigation solution per 1000 L as was used in a trial which assessed in the tolerance of five tomato cultivars ‘Alam’, ‘Majd’, ‘Asalah’, ‘Ayah’ and ‘Bahjah’ to various level of salinity.

Input	MAP	KNO_3	AN	MgS	Cu EDTA	Fe EDDHA	Zn EDTA	Mn EDTA	B_2O_3	Na Mo	CN
g.1000L^{-1}	137	560	44.5	461.5	0.5	8.5	1.2	1.2	1	0.05	437.50

MAP: Mono-ammonium phosphate; KNO_3: Potassium nitrate; AN: Ammonium nitrate
MgS: Magnesium sulphate; B_2O_3: Boric acid, NaMo: Sodium molybdate, CN: Calcium nitrate

Table 3. Plant height (cm) at termination for both winter and summer planting for five tomato cultivars ‘Majd’, ‘Alam’, Asalah’, ‘Ayah’ and ‘Bahjah’ when cultivated in the Jordan Valley, under saline solutions when NaCl at 1, 2, 3, 4 and 5g.L^{-1} respectively was added to a standard fertigation solution.

Salt concentration (g.L^{-1})	Winter planting (cm)	Summer planting (cm)
1	65.04 a[z]	21.87 a
2	63.5 ab	19.39 b
3	60.35 b	17.24 c
4	53.26 c	15.80 d
5	48.51 d	14.43 d
Cultivar		
‘Alam’	59.18 b	17.64 b
‘Asalah’	54.90 c	17.66 b
‘Ayah’	62.32 a	20.74 a
‘Bahjah’	55.73 bc	17.27 b
‘Majd’	58.55 ab	18.11 b
Winter planting	F value	p-value
Salt concentration	**65.62**	**0.0000**[y]
Cultivar	**11.69**	**0.0000**
Salt concentration * Cultivar	1.32	0.1781
Summer planting		
Salt concentration	**82.16**	**0.0000**
Cultivar	**21.16**	**0.0000**
Salt concentration * Cultivar	0.77	0.7171

[z] Values within columns with different letters are statistically different at the 95% confidence level

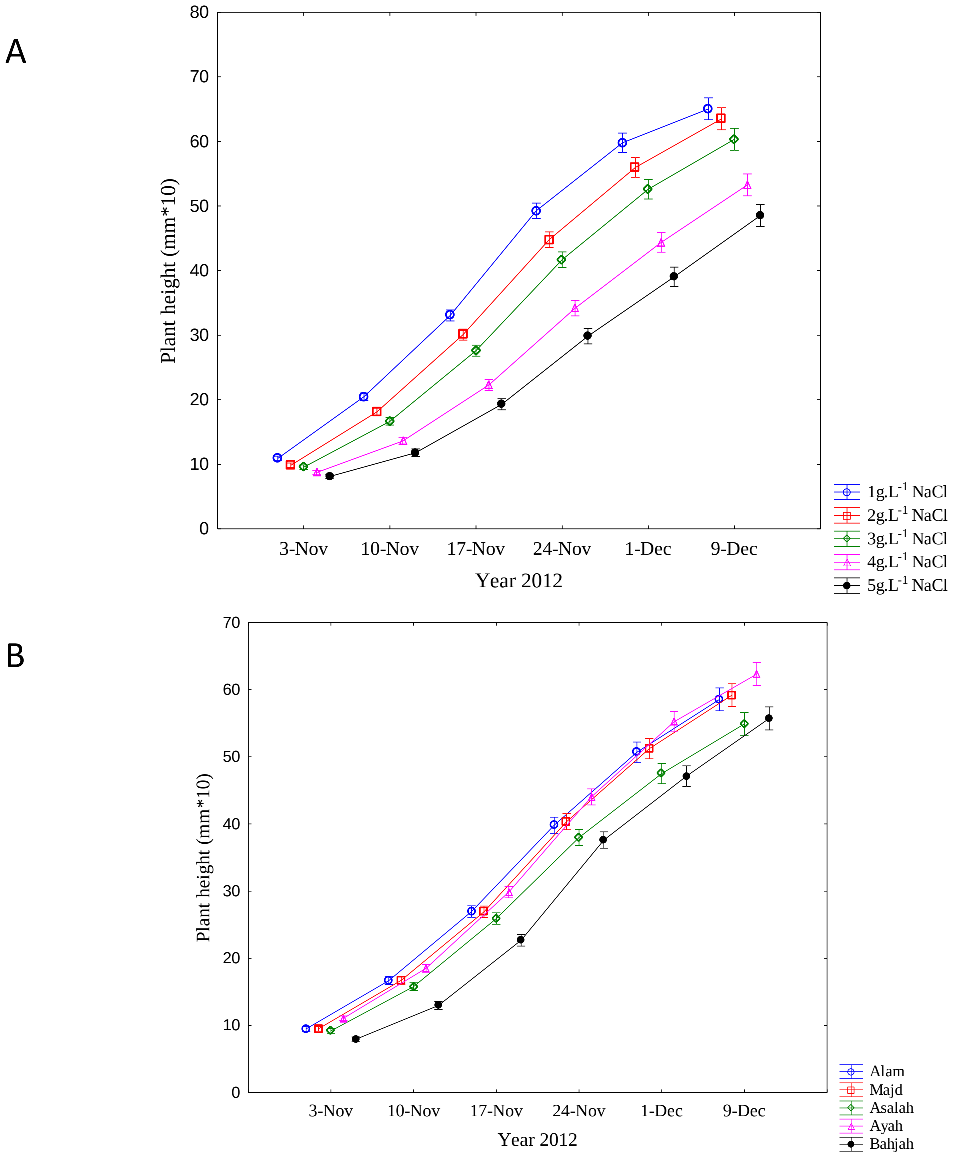
[y] p-values of interactions or main effects printed in bold is significant at the 5% confidence level

Table 4. Plant leaf number at termination for both winter and summer planting for five tomato cultivars 'Majd', 'Alam', Asalah', 'Ayah' and 'Bahjah' when cultivated in the Jordan Valley, under saline solutions when NaCl at 1, 2, 3, 4 and 5g.L^{-1} respectively was added to a standard fertigation solution.

Salt concentration (g.L^{-1})	Winter planting	Summer planting
1	9.52 a[z]	7.49 a
2	8.83 b	6.85 b
3	8.56 b	6.06 c
4	7.72 c	5.78 cd
5	7.37 c	5.4 d
Cultivar		
'Alam'	8.48 ab	6.33b
'Asalah'	8.23 b	6.34b
'Ayah'	8.63 a	7.00 a
'Bahjah'	8.24 b	6.23 b
'Majd'	8.42 ab	6.44 b
Winter planting	F value	p-value
Salt concentration	0.25	0.0000
Cultivar	**4.84**	**0.0177**[y]
Salt concentration * Cultivar	0.43	0.9697
Summer planting		
Salt concentration	**62.42**	**0.0000**
Cultivar	8.74	0.0001
Salt concentration * Cultivar	0.53	0.9325

[z] Values within columns with different letters are statistically different at the 95% confidence level.

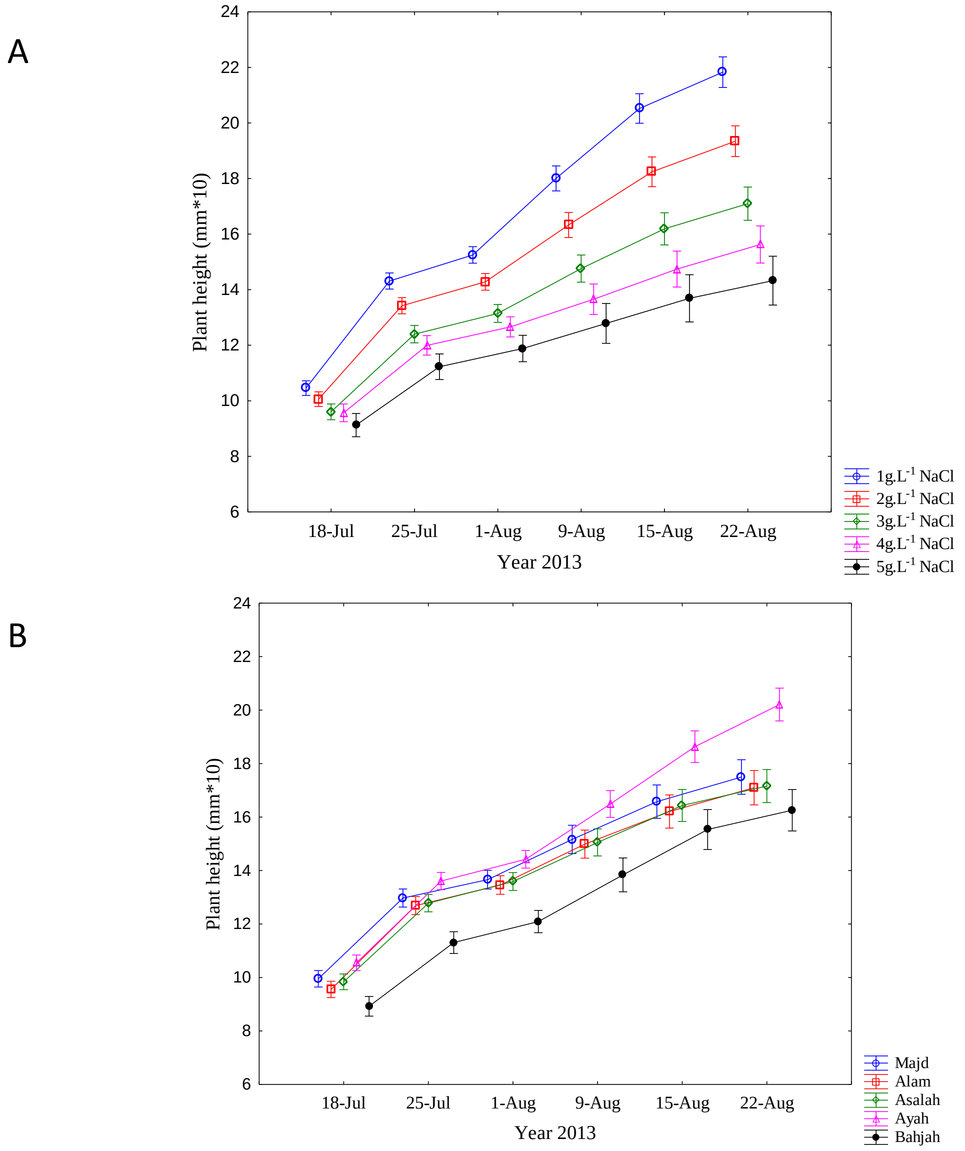
[y] p-values printed in bold is significant at the 5% confidence level



Source of variance	MS	DF	P
Salt concentration	18609	172.15	0.0000
Cultivar	3270	30.25	0.0000
Time	185495	9937.74	0.0000
Time * Salt concentration	**828**	**44.38**	**0.0000**[z]
Time * Cultivar	**102**	**5.48**	**0.0000**
Salt concentration*Cultivar	147	1.36	0.1591
Time*Salt concentration*Cultivar	18	0.98	0.5417

[z] p-values for interactions or main effects printed in bold is significant at the 5% confidence level

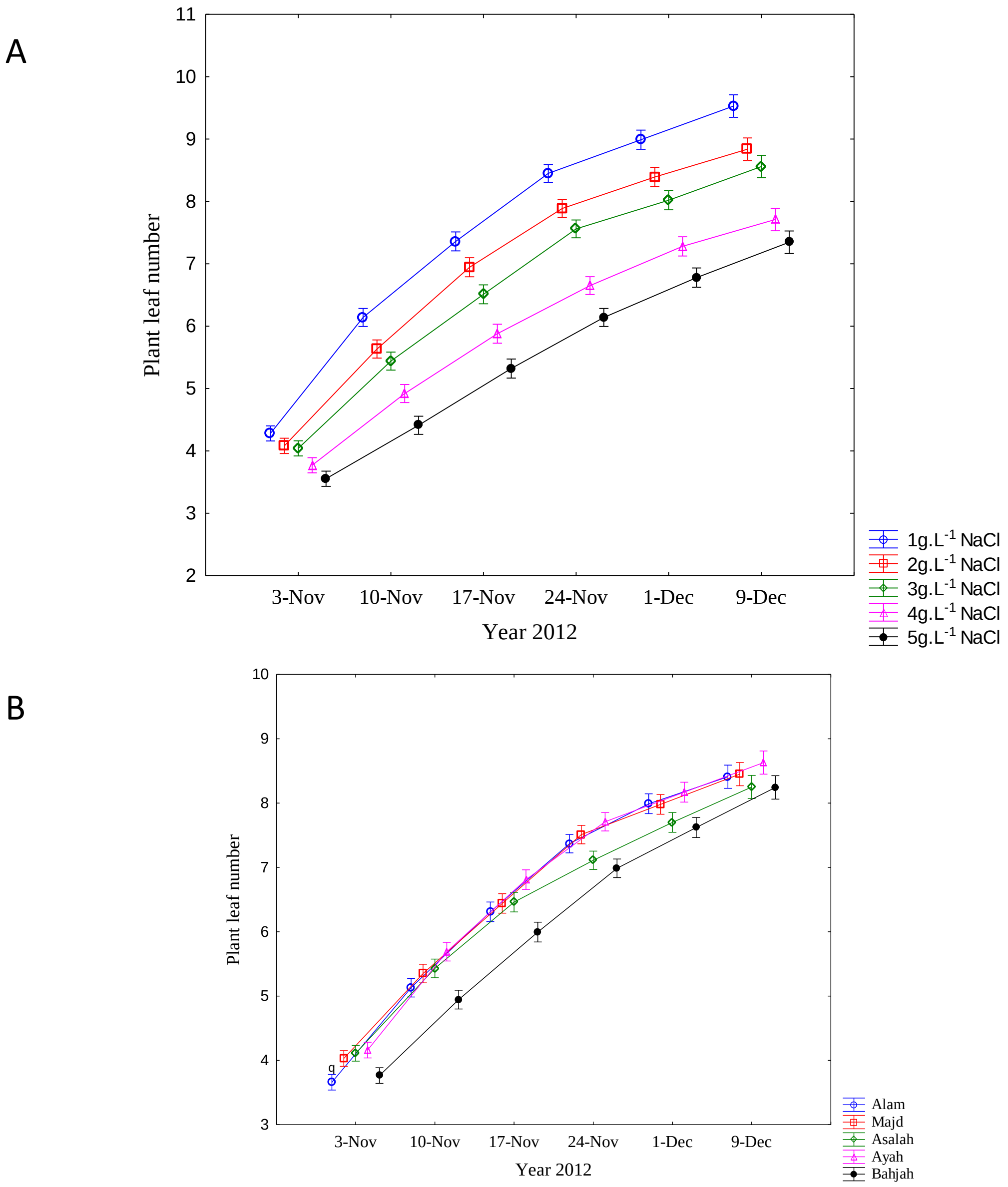
Fig. 1. Plant height weekly increase (cm) of the five determinate tomato cultivars ‘Alam’, Majd’, ‘Asalah’, ‘Ayah’ and ‘Bahjah’ (B) when subjected to a range of saline solutions induced by NaCl at 1, 2, 3, 4 and 5 g.L^{-1} (A) as monitored over a six-week period from 3 Nov-9 Dec 2012 in a winter planting in the Jordan Valley.



Source of variance	MS	DF	P
Salt concentration	1338.8	81.17	0.0000
Cultivar	345.5	20.95	0.0000
Time	2726.5	1546.96	0.0000
Time * Salt concentration	**64.9**	**36.82**	**0.0000**^{z}
Time * Cultivar	**12.5**	**7.10**	**0.0000**
Salt concentration*Cultivar	16.5	1.00	0.4525
Time*Salt concentration*Cultivar	1.4	0.80	0.8950

^{z}p-values in printed in bold is significant at the 5% confidence level

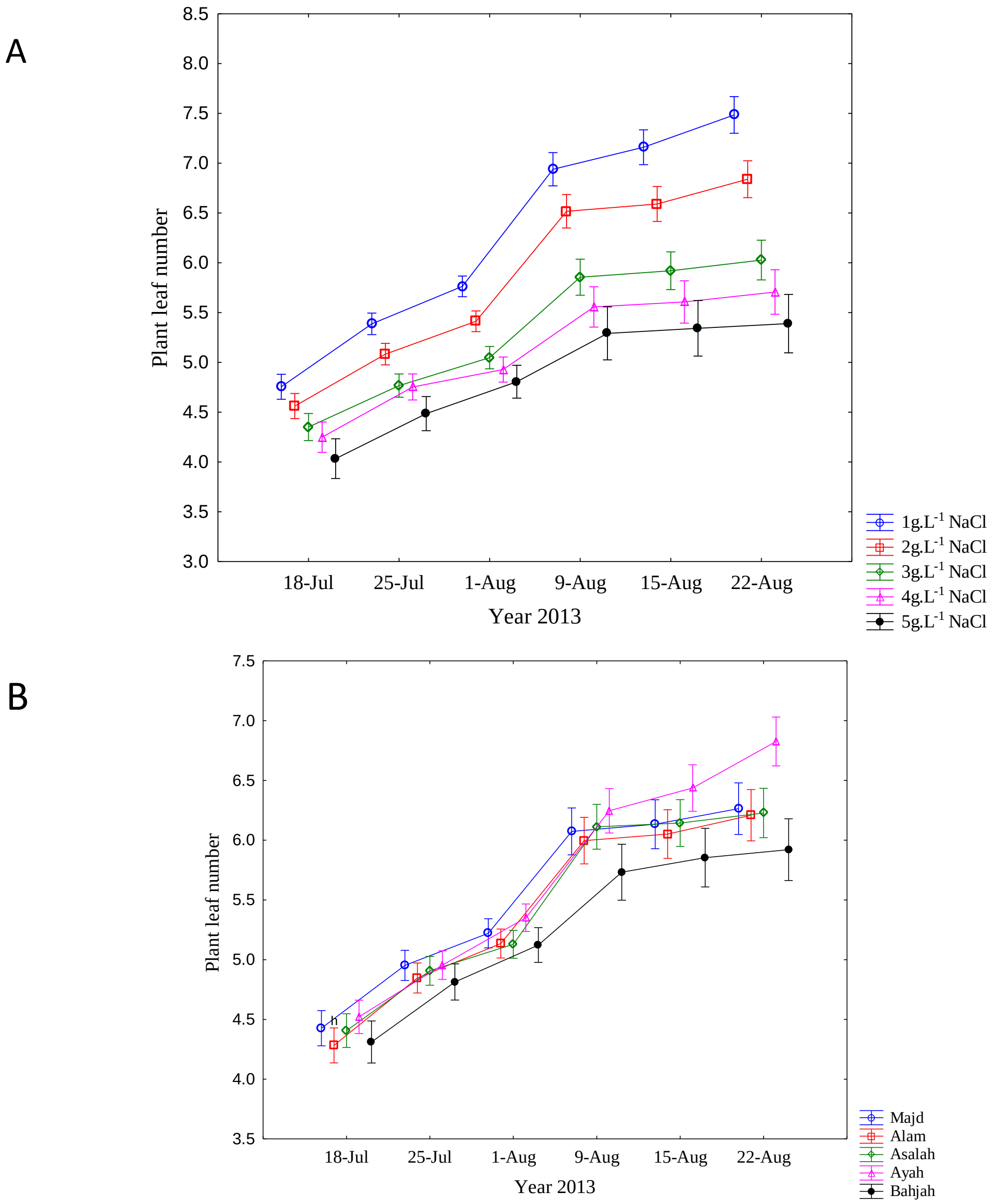
Fig. 2. Plant height weekly increase (cm) of the five determinate tomato cultivars ‘Alam’, Majd’, ‘Asalah’, ‘Ayah’ and ‘Bahjah’ (B) when subjected to a range of saline solutions induced by NaCl at 1, 2, 3, 4 and 5 g.L^{-1} (A) as monitored over a six-week period from 18 July -22 August 2013 in a summer planting in the Jordan Valley.



Source of variance	MS	DF	P
Salt concentration	328.1	187.28	0.0000
Cultivar	28.9	16.49	0.0000
Time	1412.1	4006.20	0.0000
Time * Salt concentration	**6.1**	**17.44**	**0.0000**^{z}
Time * Cultivar	**1.8**	**4.98**	**0.0000**
Salt concentration*Cultivar	1.8	1.00	0.4528
Time*Salt concentration*Cultivar	0.4	1.04	0.3892

^{z}p-values in printed in bold is significant at the 5% confidence level

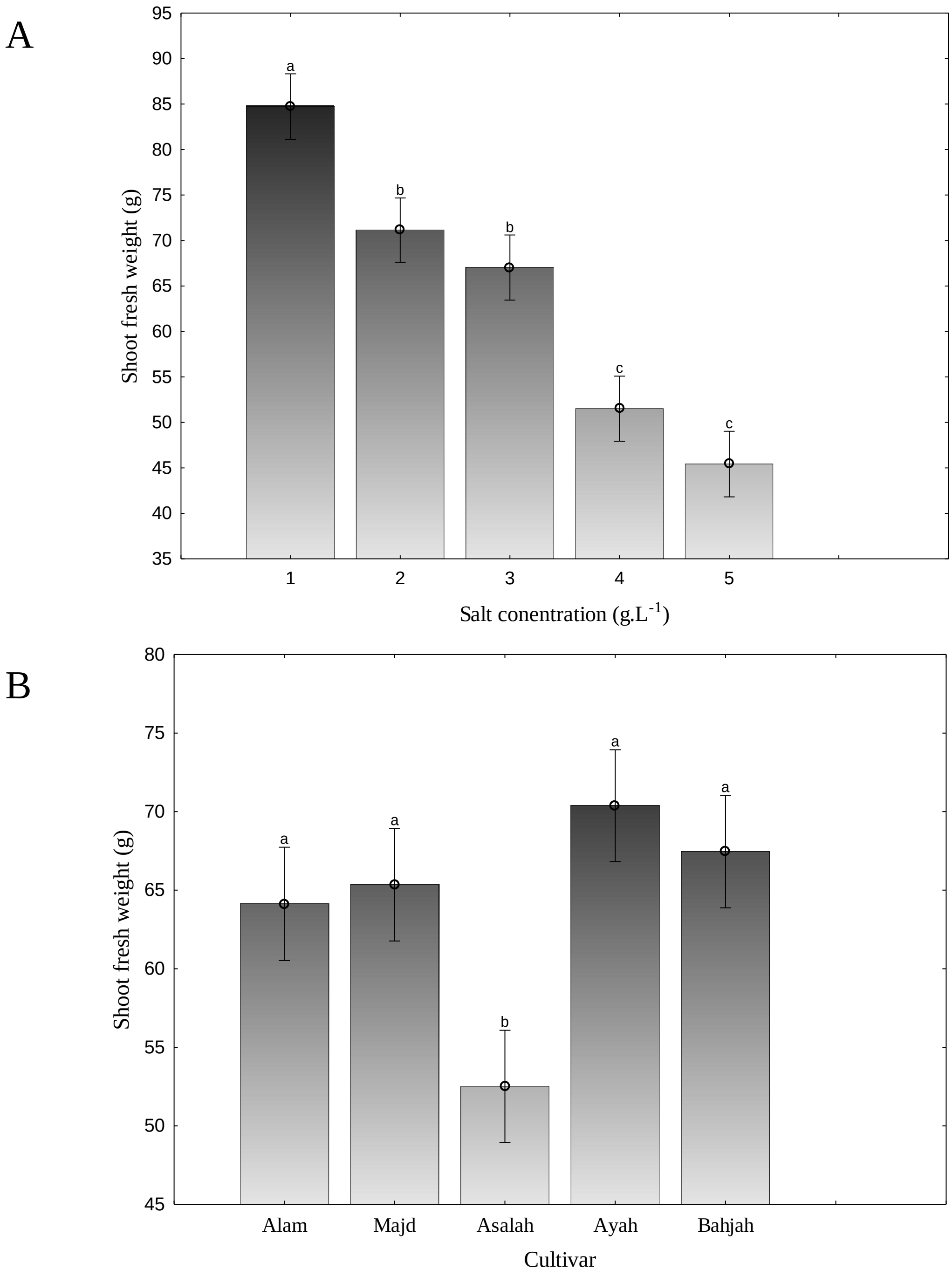
Fig. 3. Plant leaf number weekly increase of the five determinate tomato Cultivars ‘Alam’, ‘Majd’, ‘Asalah’, ‘Ayah’ and ‘Bahjah’ (B) when subjected to a range of saline solutions as induced by NaCl at 1, 2, 3, 4 and 5 g.L^{-1} (A) as monitored over a six-week period from 3 Nov- 9 Dec 2012 in a winter planting.



Source of variance	MS	DF	P
Intercept	59447.45	31036.75	0.0000
Salt Concentration	125.42	65.48	0.0000
Cultivar	9.51	4.96	0.0000
Time	196.71	768.88	0.0000
Time * Salt concentration	**4.28**	**16.74**	**0.0000**^{z}
Time * Cultivar	**0.84**	**3.28**	**0.0000**
Salt Concentration*Cultivar	1.44	0.75	0.7385
Time*Salt concentration*Cultivar	0.13	0.52	0.9998

^{z}p-values in printed in bold is significant at the 5% confidence level

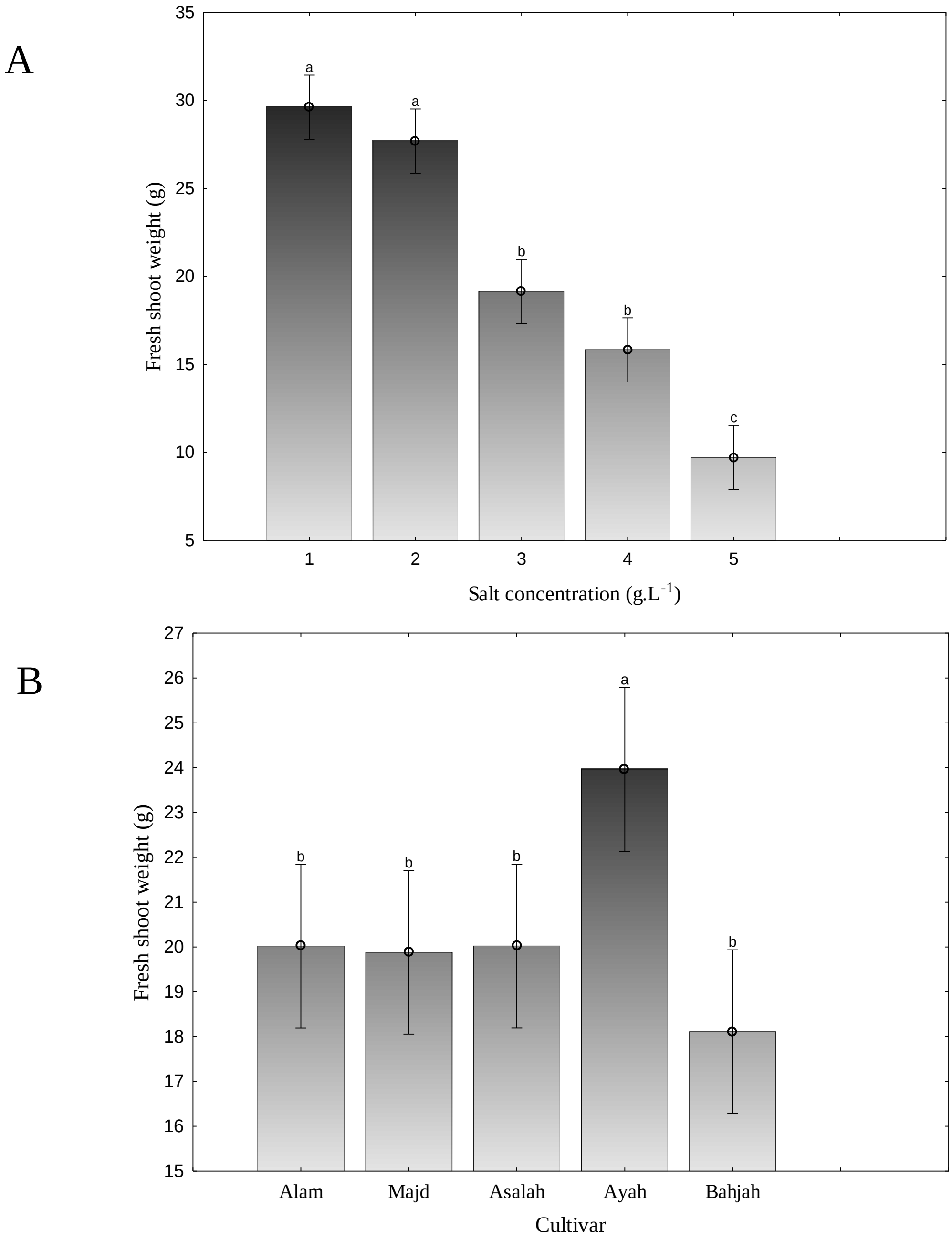
Fig. 4. Plant leaf number weekly increase of the five determinate tomato cultivars ‘Alam’, ‘Majd’, ‘Asalah’, ‘Ayah’ and ‘Bahjah’ (B) when subjected to a range of saline solutions as induced by NaCl at 1, 2, 3, 4 and 5 g.L^{-1} (A) as measured over a six-week period from 18 Jul to 22 Aug 2013 in a summer planting.



Source of variance	F	P
Salt concentration	**79.800**	**0.0000**
Cultivar	**15.576**	**0.0000**^{z}
Salt concentration * Cultivar	1.519	0.0900

^{z}p-values in printed in bold is significant at the 5% confidence level

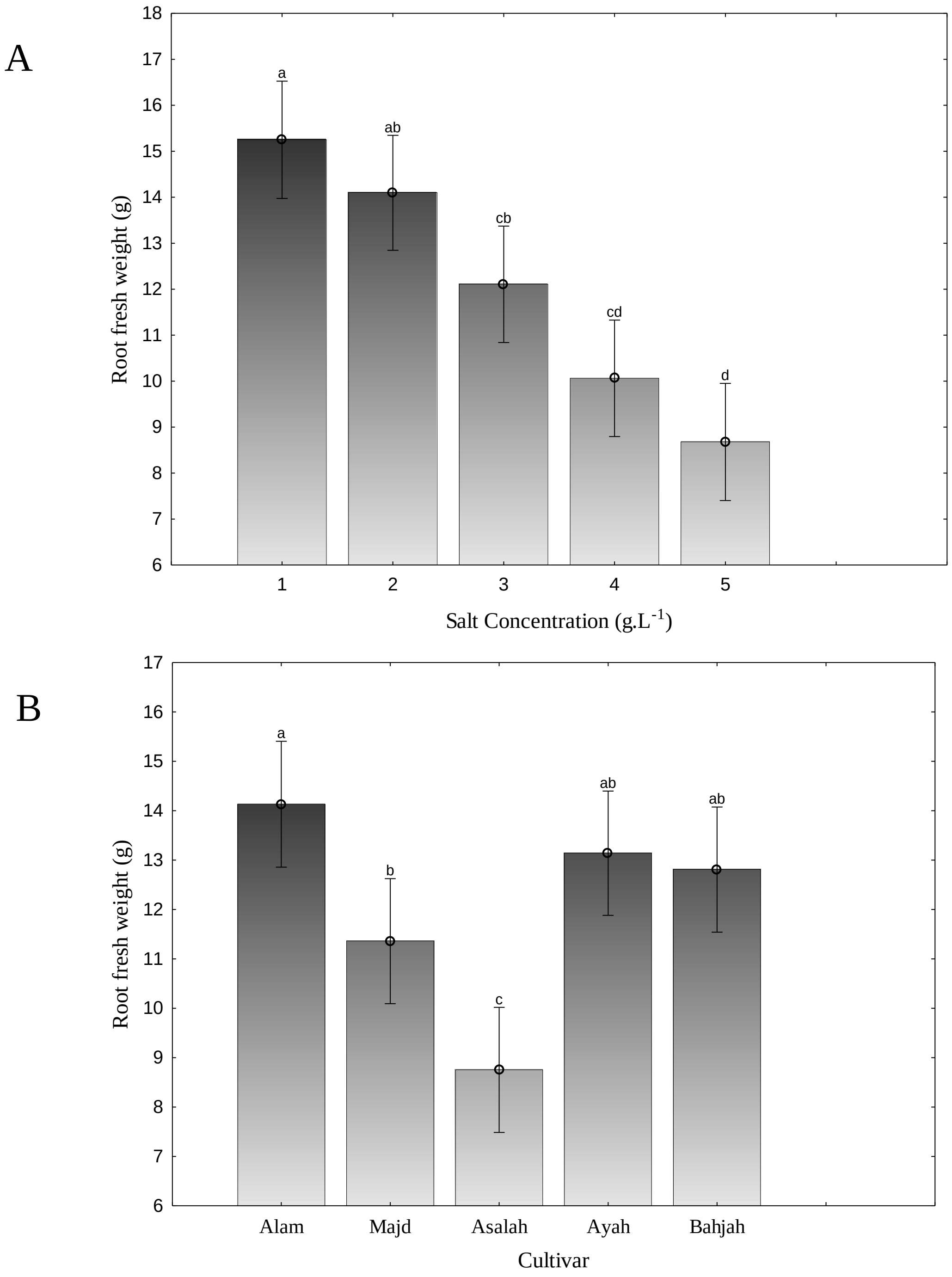
Fig. 5. Plant fresh shoot weight (g) of a winter planting of five determinate tomato cultivars ‘Alam’, ‘Majd’, ‘Asalah’, ‘Ayah’ and ‘Bahjah’ (B) as evaluated on 15 Dec. 2012 in the winter planting at harvest when cultivated in the Jordan Valley under saline solutions when NaCl at 1, 2, 3, 4 and 5g.L^{-1} (A) respectively was added to a standard fertigation solution.



Source of variance	F	P
Salt concentration	**79.609**	**0.0000**
Cultivar	**5.346**	**0.0000**[z]
Salt concentration* Cultivar	1.041	0.4109

[z] p-values in printed in bold is significant at the 5% confidence level

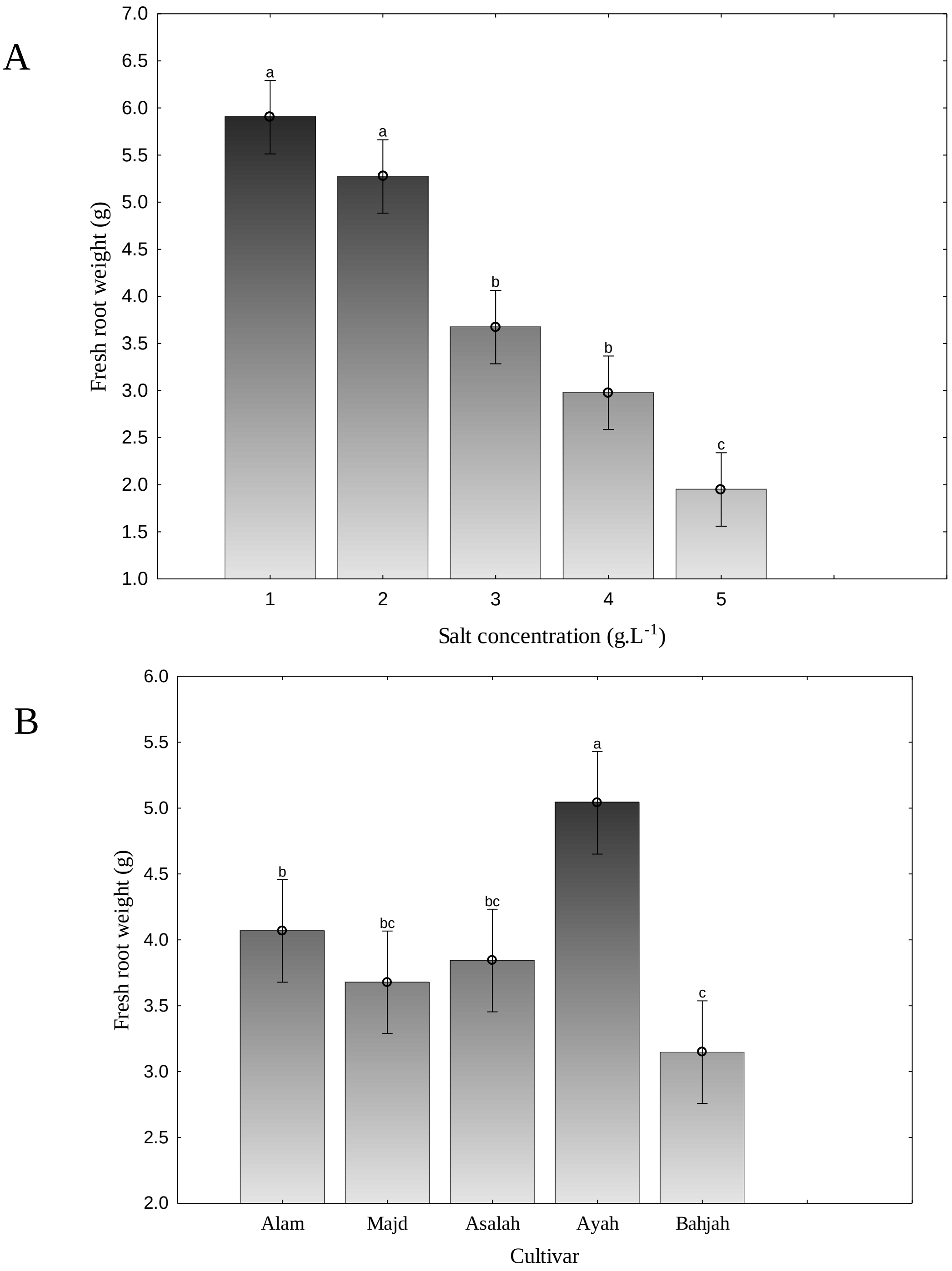
Fig. 6. Plant fresh shoot weight (g) as evaluated on 25 Sep. 2013 in the summer planting at harvest of five determinate tomato cultivars ‘Alam’, ‘Majd’, ‘Asalah’, ‘Ayah’ and ‘Bahjah’ (B) when cultivated during a summer planting in the Jordan Valley under saline solutions when NaCl at 1, 2, 3, 4 and 5 g.L^{-1} (A) respectively was added to a standard fertigation solution.



Source of variance	F	P
Salt concentration	**18.744**	**0.0000**
Cultivar	**10.948**	**0.0000**[z]
Salt concentration* Cultivar	0.901	0.5677

[z] p-values in printed in bold is significant at the 5% confidence level

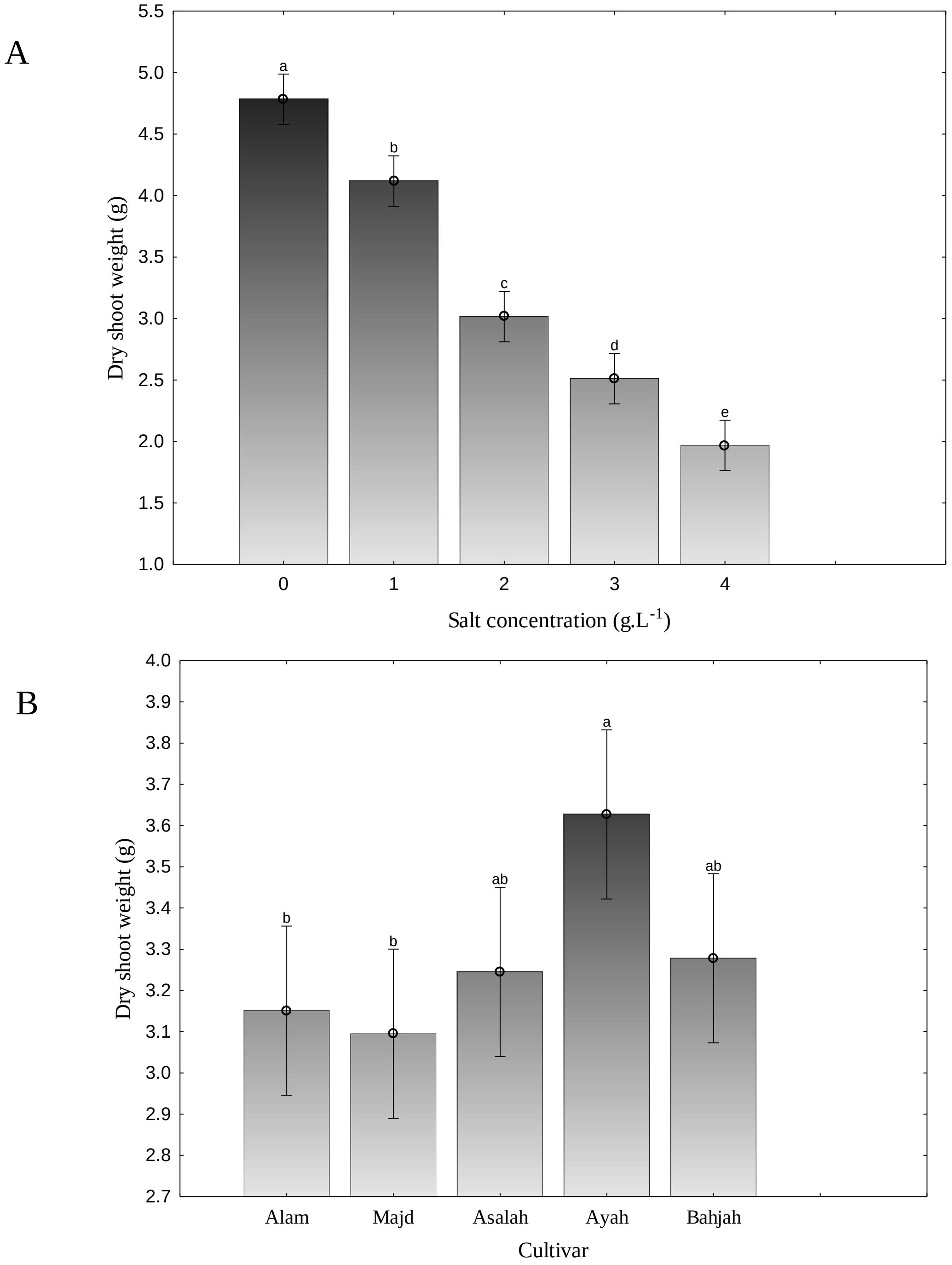
Fig. 7. Plant fresh root weight (g) as evaluated on 15 Dec. 2012 in the winter planting at harvest of five determinate tomato cultivars ‘Alam’, ‘Majd’, ‘Asalah’, ‘Ayah’ and ‘Bahjah’ (B) when cultivated in the Jordan Valley during a winter planting under saline solutions when NaCl at 1, 2, 3, 4 and 5 g.L^{-1} (A) respectively was added to a standard fertigation solution.



Source of variance	F	P
Salt concentration	**67.275**	**0.0000**
Cultivar	**12.299**	**0.0000**[z]
Salt concentration* Cultivar	0.904	0.5647

[z] p-values in printed in bold is significant at the 5% confidence level

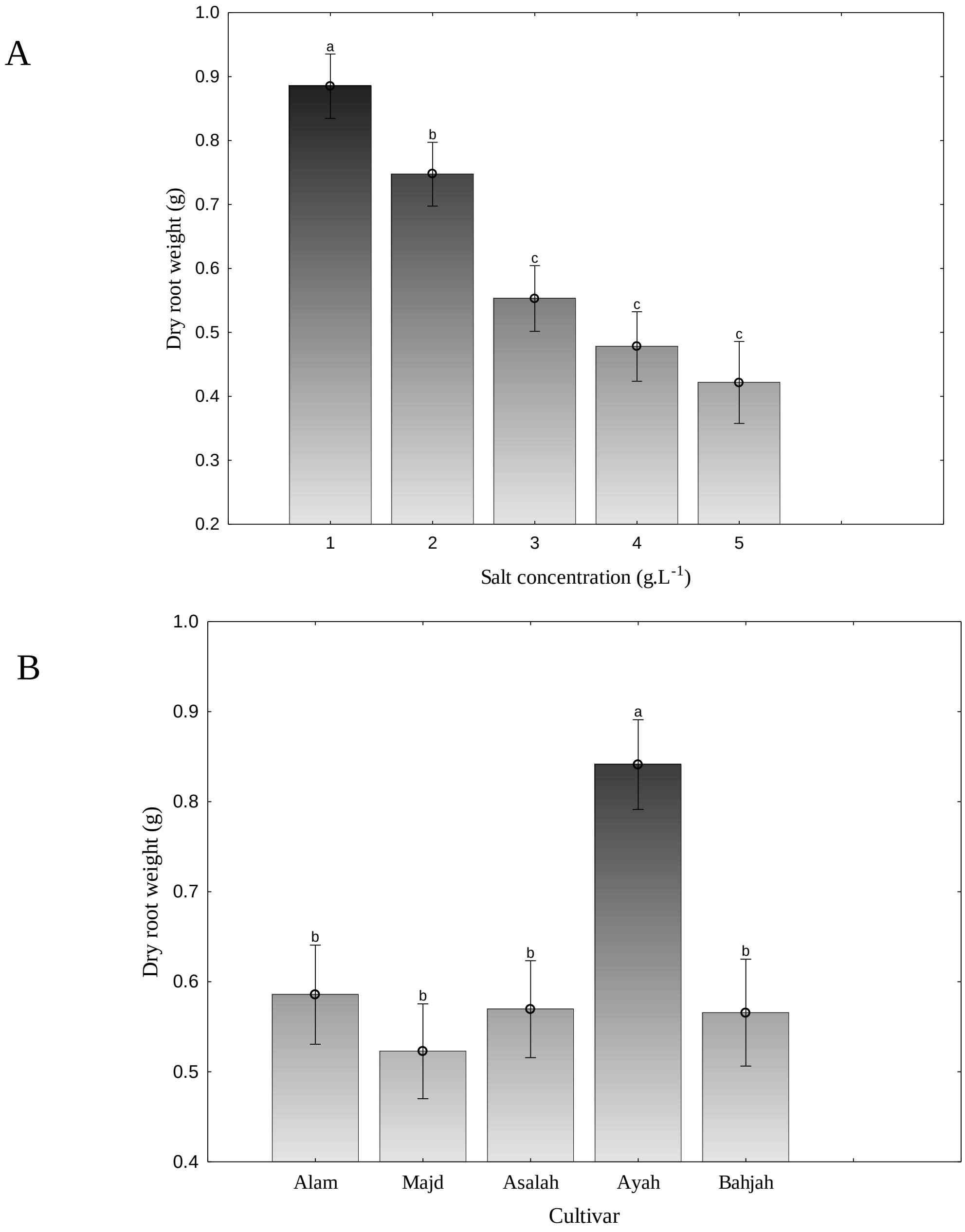
Fig. 8. Plant fresh root weight (g) as evaluated on 25 Sep. 2013 in the summer planting at harvest of five determinate tomato cultivars ‘Alam’, ‘Majd’, ‘Asalah’, ‘Ayah’ and ‘Bahjah’ (B) when cultivated during the summer planting under saline solutions when NaCl at 1, 2, 3, 4 and 5 g.L^{-1} (A) respectively was added to a standard fertigation solution.



Source of variance	F	P
Salt concentration	**122.574**	**0.0000**
Cultivar	**3.957**	**0.0000**^{z}
Salt concentration* Cultivar	1.599	0.0651

^{z}p-values in printed in bold is significant at the 5% confidence level

Fig. 9. Plant dry shoot weight (g) as evaluated on 20 Oct. 2013 in the summer planting at harvest of five determinate tomato cultivars 'Alam', 'Majd', 'Asalah', 'Ayah' and 'Bahjah' (B) when cultivated during a summer planting in the Jordan Valley under saline solutions when NaCl at 1, 2, 3, 4 and 5 g.L^{-1} (A) respectively was added to a standard fertigation solution.



Source of variance	F	P
Salt concentration	**49.940**	**0.0000**
Cultivar	**24.293**	**0.0000**[z]
Salt concentration* Cultivar	0.998	0.4575

[z] p-values in printed in bold is significant at the 5% confidence level

Fig. 10. Plant dry root weight (g) as evaluated on 20 Oct. 2013 in the summer planting at harvest of five determinate tomato cultivars ‘Alam’, ‘Majd’, ‘Asalah’, ‘Ayah’ and ‘Bahjah’ (B) when cultivated during a summer planting in the Jordan Valley under saline solutions when NaCl at 1, 2, 3, 4 and 5 g.L^{-1} (A) respectively was added to a standard fertigation solution.

Paper 3: Salinity tolerance of two commercially important banana cultivars ‘Grand Nain’ and ‘Paz’ of the Jordan Valley when cultivated under increasing levels of fertigation salinity

ABSTRACT

Salinity, as a major factor limiting factor in banana production of the Jordan valley, was studied in a summer and winter planting, as carried out in August 2012 for 45 days and in January 2013 for 90 days respectively, for two widely planted banana cultivars, ‘Grand Nain’ and ‘Paz’. Each cultivar were exposed to five different levels of salinity as established through the addition of NaCl to the fertigation tank at concentrations of 1, 2, 3, 4 and 5 g.L^{-1} and 1, 1.75, 2.5, 3.25 and 4 g.L^{-1} for the summer and winter planting respectively. Parameters recorded included weekly measurements of plant height and leaf number, the final fresh root and shoot weight for both plantings at harvest, and dry root and shoot weight for the winter planting at harvest. Increased salinity was strongly associated with reduced plant height development over the growing season, as well as a final reduced plant height at harvest, reduced plant leaf production over the growth season, a lower final plant leaf number at harvest, as well as a lower fresh shoot and root weight including reduced dry shoot and root weight at harvest. Yet, this initial study provided no clear evidence to suggest significant differences between the two cultivars in their tolerance to salinity, therefore additional studies which would extend up to harvest and may include more banana cultivars for comparison and a wider range of production criteria to be considered in the assessment is recommended in future.

ADDITIONAL INDEX WORDS.

Saline soils, Plant height weekly development, Leaf number weekly development, Fresh root weight, Fresh shoot weight, Dry root weight, Dry shoot weight, Abiotic stress.

Introduction

Soil and water salinity in arid regions are increasingly becoming a problem of international scale as the degrading of agricultural soil fertility by salinity is spreading all over arid and semi-arid regions of the world (Rus et al., 2002). Globally, it was reported that more than 770 000 km^2 of arable land are already subjected to secondary salinization, with a projected 20 % of the irrigated areas and about 2 % of the established agricultural lands being affected (FAO STAT, 2000). In addition, the estimated area exposed to salinity is expected to continue to increase in addition to the existing salt-affected soils which are already considered to be dominant in both arid and semi-arid regions where annual precipitations are not adequate to meet the evapotranspiration needs of crops, thus almost always requiring additional crop irrigation, often with saline water (Luchli and Epstein, 1990).

Parada and Das (2006) reported that salinity is a major abiotic factor limiting plant growth and fruit yield. Salinity enhances osmotic- and toxic effects that leads to physiological, morphological and biochemical modifications, such as growth inhibition, yield reduction, lowered rates of photosynthesis and respiration, nutritional deficiencies and inhibition of protein synthesis (Ashraf and Foolad, 2007). A main effect of salinity on plants is an imbalance in leaf water potential, with dehydration at the cellular level (Herna'ndez et al., 1999), where loss of leaf water potential leads to stomatal closure, restricted CO_2 diffusion into the leaves, and inevitable results in a decrease in net photosynthetic rate (Herna'ndez and Almansa, 2002).

Banana as a crop is rated as the fourth most important as a global food commodity, following rice, wheat and maize respectively (Frison and Sharrok, 1999). Banana is produced in about 100 countries, with the total area under cultivation estimated at about 10 million hectares and with annual production figures of approximately 88 million metric tonnes (Frison and Sharrok, 1999). In Jordan, 90 000 to 100 000 metric tonnes of banana have been produced annual until 2010 (personal communication 2013, Mr. A. Tarteer, president of the Jordanian Union of Banana Growers), where after production declined over the last three years to between 55 000 and 60 000 MT, mostly because of poor quality irrigation water due to increased salinization. At this stage 85% of all banana farms in Jordan Valley is now required to implement water treatment stations to maintain productivity. In general, banana is considered sensitive to salinity (Israeli et al., 1986) with preferred production conditions on soils with a pH of above 5 and soil electrical conductivity (EC) of below 0.15 $dS.m^{-1}$ (Newley and Akehurst, 2008). Therefore soil salinity is known to seriously impact on both the quality and quantity of banana production. A study by Gomes et al. (2001) on the effect of salinity on five banana cultivars ('Pacovan', 'Nanicao', 'Caipira', 'FHIA 18', and 'Calcutta') reported a reduction of about 70% in dry weight of leaves and of about 50% in leaf area when plants were treated with 100 mM NaCl solution. This finding was supported by a study on growth-related traits of micro-propagated banana plants where decreased chlorophyll content was reported to be accompanied by a significant decrease in protein and carbohydrate content for banana that were cultivated with increasing salinity (Ikram-Ul Haq et al., 2011).

In a study conducted in Egypt the two banana cultivars ‘Grand Nain’ and ‘Williams’ were compared for various production traits when grown in a clay:sand mixture of 2:1, whilst being fertigated with nutrient solutions to which NaCl was added at either 2 and 3 g.L^{-1}. Results showed that in most cases ‘Grand Nain’ performed significantly better in both vegetative growth and chemical composition, except for the rate of senescence and for leaf calcium and sodium content that were higher for ‘Williams’ (Abd El-Latef et al., 2007). However, comparative studies considering production conditions for banana under saline conditions in the Jordan Valley and focussing on cultivars that are common used in this region is not available.

This study thus aims to assess whether differences in tolerance to NaCl salinity exist between two banana cultivars, ‘Grand Nain’ and ‘Paz’, that are commonly cultivated in the Jordan Valley. Salinity as induced by increasing the NaCl concentration range and by comparing a summer and winter planting was used to provide insight into possible interactions that may occur between salt concentration and cultivar. In addition the impact of similar saline conditions on vegetative growth in terms of weekly increase in pseudo stem height, weekly increase in leaf number, and fresh weights and dry weights at harvest was recorded. This study has an overarching purpose of providing recommendations to farmers to assist in choosing the most suitable cultivar for salinity conditions. Future research should focus on studies which extends up to harvest and also includes assessing the use of ameliorants to elicite a tolerance to saline conditions in the respective cultivars.

Materials and Methods

Planting material. The two most commonly planted banana cultivars (*Musa* spp.) in the Jordan Valley, namely ‘Grand Nain’ and ‘Paz’, were compared in a winter- as well as in a summer planting, using a randomized complete block design (RCBD) with 20 replicates per treatment combination. Tissue culture-produced plantlets as supplied by Rahan Meristem (meristem@rahan.co.il) were received at the two to three true leaf stage. Plantlets were planted in 1.2 L bags in a media of 1:1 peat moss:coco peat, where after plants were kept at the Modern Technical Nursery, South Shoonah (GPS coordinates 31 52` 16.85”N, 35 37` 21.35”S) for a hardening period of two weeks, before being transplanted at the four to five leaf stages, for both the summer and winter planting. Each planting consisted of 100 plants per cultivar. After hardening was completed, plants were transplanted from the planting bags into pots (26 x 26 cm), filled with typical saline, silty-clay soils of the Jordan valley (Table 1).

Abiotic conditions. Soil analysis was done by the Arab Centre for Engineering Studies LTD (www.aces-int.com) (Table 1). Pots were placed for the entire duration of the trial under a tunnel structure covered with 60% shade black netting, with an additional plastic covering which was erected on rainy days to exclude any possible precipitation. For the winter planting, the plastic cover was provided at intermittent periods during the trial which included: 18 January – 8 March, 14-17 March, 22-23 March, 29 March – 3 April, and 12-13 April 2012 respectively. For the summer planting the plastic cover was not used at all due to the absence of any rain incidences.

The summer planting was done on 11 August 2012 and was terminated on 2 October, eight weeks later, whilst the winter planting was scheduled for 18 January 2013 and were terminated on 25 April 2013, thirteen weeks later. The latter trial was extended due to cold weather which resulted in very slow plant growth during the first five weeks. Temperature at the cultivation site ranged between 22-30˚C at day and 12-18 ˚C at night in winter compared to 40-46˚C at day and 30-36 ˚C at night during summer. Relative humidity varied from 40-70%, depending on the season.

Nutrition. Pots from both planting dates were fertigated on a daily basis from five solutions placed in each of five 1000L capacity tanks. Each tank contained the same fertilizer blend (excluding calcium), but differed in their respective NaCl concentrations. The fertilizer blend selected was formulated especially to optimize all aspects of banana production and are routinely used by banana producers of the Jordan Valley and nearby countries. Nutrients ratios were as follow: N: 1; P: 0.75; K: 2.6; Ca: 0.5; Mg: 0.25; S: 0.6 and trace elements (a mix of Fe, Zn, Mn, Cu, B & Mo) at a ratio of 0.19 respectively.

Each of the five tanks per planting contained 217g of potassium nitrate (KNO_3), 448g of potassium sulphate (K_2SO_4), 270g of mono-ammonium phosphate (MAP), 461.5g of magnesium sulphate ($MgSO_4$), 0.5g of copper (chelated on EDTA), 8.5g of iron (chelated on EDDHA), 1.2g of manganese (chelated on EDTA), 1.2g of zinc (chelated on EDTA), 1g of boric acid (B_2O_3) and 0.05g of sodium molybdate (Na_2MoO_4) per a total of 1000L respectively (Table 2). The blend in each tank was agitated with a suitable mixer on a weekly basis to ensure homogeneity of the solution. An additional sixth tank which contained only calcium ($CaNO_3$) at 291.7 g.1000L^{-1} was used in combination with the fertilizer blend (Table 2).

The NaCl content of each tank which constituted one of the main treatments differed between that used for the summer and winter plantings. A concentration range of 1, 2, 3, 4 and 5 g.L^{-1} respectively was used in the summer planting, while for the winter planting the NaCl concentration was adapted to circumvent the high plant mortality than was to be expected with plants established under summer planting conditions. The NaCl concentration was thus amended for the latter planting date to range from 1, 1.75, 2.5, 3.25 and 4 g.L^{-1} respectively.

Daily fertigation was done from the standard mixture tanks, except for once a week when only $CaNO_3$ was provided. Fertigation rates were applied to ensure 20% runoff per pot during the first 30 minutes after fertigation. For the summer 2012 planting date, an initial 1000 ml per pot were applied during the first week, where after the delivery was reduced to 800 ml by the third week (25 August) until the termination of the trial. For the winter 2013 planting, an initial fertigation rate of 1000 ml per pot was scheduled, where after it was reduced by 28 ml in January to 800 ml per pot, with final reduction on 31 January to 600 ml per pot for the remainder of the trial period. This fertigation rate was based on weekly observations of the runoff quantity as affected with environmental conditions such as temperature and humidity. Fertigation was scheduled daily to occur in the morning period between 05.00 and 07.00 in order to reduce the incidence of evaporation. The pH and EC values for the respectively tanks were monitored weekly during the first three to four weeks from the trial initiation. In addition, an average soil pH of between 6 and 6.8 was recorded for pots throughout the trial. No pesticide or fungicide applications were required during either of the two trials, mainly due to the netting coverage which controlled pests' infections and created microclimatic conditions which was not conducive for pathogen infection.

Data collection. Measurements were taken on weekly basis for both planting dates. For the summer planting date plant height (pseudo stem length, measured in cm) as well the number of leaves of each plant were recorded. The fresh shoot and root weight (g) were recorded at the termination of the trial. For the winter planting date, in addition to weekly plant height (pseudo stem length, measured in cm) and leaf count recordings, fresh- and dry shoot and root weights (g) was also documented respectively.

Experimental design. A randomized complete block design was used with 20 replicates per treatment combination where cultivar and salinity concentration were considered the main effects. Growth parameters like the plant height weekly increase average and leaf number weekly increase average was analysed by a Repeated Measured ANOVA (RANOVA) in Statistica 13.2, whilst fresh weight and dry weight were analysed by a comparison of means of a linear models ANOVA and using Benferroni's posthoc separation test in Enterprise guide, SAS.

Results and Discussion

Summer planting - Plant height over the growth season (2012). The weekly increase in plant height over the growing season showed an interaction between salt concentration, cultivar and time (Fig. 1). An increase in salinity concentration resulted in a significant reduction in weekly growth development in terms of increased height over time, with the upper range of the salt concentration at 3 and 4 g.L^{-1} being the most severe in terms of its impact on average plant height weekly increment (Fig. 1A). Salinity appeared to affect the two different cultivars similarly, even though 'Paz' did scored a slightly higher average weekly plant height development of 6.2cm, compared to 'Grand Nain' that scored 6cm (Fig. 1B). This apparent higher tolerance to salinity of 'Paz' was more evident during the mid-term growth season, as initial and final plant height values were comparable. Kurum et al. (2013) reported comparative results on pumpkins where a distinct decrease in shoot length increments of plants was noted with increased salinity. Similarly, Abd El- Latef et al. (2007) confirmed the sensitivity of the banana cultivars 'Grand Nain' and 'William' to salinity when grown in Egypt, as plant height was negatively affected with salinity levels and more affected at 3000 ppm than 2000 ppm NaCl.It was also noticed that 'Williams' cultivar was more affected than cultivar 'Grand Nain'

Winter planting - Plant height over the growth season (2013). For the winter planting a different trend between salt concentration, cultivar and time was noted as no interaction emerged for the parameter plant height over the growth season (Fig. 2). Similarly, as in the summer planting, no interaction between salt concentration and cultivar was evident, nor did an interaction occur between time and cultivar or between salt concentration and cultivar (Fig. 2). An interaction between time and salt concentration was evident (Fig. 2). Similar to the summer planting, the increase in salinity concentration resulted in a significant reduction in weekly growth development with respect to increased height over time, especially so at the three higher concentration levels (Fig. 2A). However, the effect on average plant height weekly increment with increasing salt concentration did not appear to differ between cultivars, where 'Grand Nain' scored a comparable average weekly plant height development of 12.1 cm to that of 'Paz' that scored a mean value of 11.8 cm (Fig. 2B).

In general, plants established in the winter planting are able to perform considerably better than the summer planting, probably due the accumulative effect of more moderate environmental temperatures and a lower salt concentrations range in the fertigation solution in the winter planting compared to the summer planting.

Summer planting - Plant height at harvest (2012). No interaction was recorded between salt concentration and cultivar for final plant height at harvest (Table 3). However, increasing salt concentration significantly affected the final plant height at the termination of the trial as plant height were clearly stunted by increasing salinity (Table 3). Similar results of a reduced plant height with salinity were reported by Rameeh and Gerami (2015) on rape seed using three levels of salinity to deliver fertigation solutions at 0, 6, and 12 dS.m^{-1} using NaCl and $CaCl_2$ solutions to elevate the level of salinity. Cultivars ‘Grand Nain’ and ‘Paz’ produced comparative final plant heights at harvest where ‘Grand Nain’ produced a final plant height of 9.5 cm compared to ‘Paz’ at 9.25 cm (Table 3). The stress conditions of summer in combination with increased salinity severely impacted on plant height, when being compared with a lower salinity under winter production conditions.

Winter planting - Plant height at harvest (2013). For the winter planting no interaction between salt concentration and cultivar was reported for final plant height (Table 3), with increasing salt concentration being the only factor that significantly affecting the final plant height (Table 3No significant difference between cultivars was observed with ‘Paz’ producing plants at harvest of 18.9 cm compared to that of ’Grand Nain’ at 19 cm (Table 3).

Summer planting – Plant leaf number over the growth season (2012). The weekly increase in plant leaf number over the growing season did not show any interaction between salt concentration, cultivar and time (Fig. 3). Also, no interaction between salt concentration and cultivar was found, nor between time and cultivar, or between time and salt concentration (Fig. 3). Although the salt concentration did affect the production of leaves over the growth season, it was found to be relatively insensitive to increasing salt concentrations (Fig. 3A). Also, no significant difference between cultivar was noted for leaf number as the average leaf number for ‘Grand Nain’ was recorded at an average of 4.4 leaves, with values for ‘Paz’ at rated at 4.2 leaves (Fig. 3B).

Winter planting – Plant leaf number over the growth season (2013). Similar to the summer planting, the weekly increase in plant leaf number over the growing season for the winter planting did not show any interaction between salt concentration, cultivar and time (Fig. 4). Also, no interaction between salt concentration and cultivar was found, nor between time and cultivar, yet a strong interaction between time and salt concentration was evident (Fig. 4). Increasing salt concentration affected the plant leaf number significantly over the growth season between salt concentrations, to the extent that no leaves were produced in the highest salt concentration treatment over the five last remaining weeks prior to the termination of the trial (Fig. 4A). In a study conducted on Fenugreek (*Trigonella foenum-graecum* L.) in India (Kapoor and Pande, 2015) leaf number was similarly reduced with increasing salt concentration.

No significant difference between cultivar performance with regard to number of leaves could be detected, also for the winter planting, as the average leaf number of ‘Grand Nain’ was recorded at 7.08 and that for ‘Paz’ to be at 7.05 leaves (Fig. 4B).

Summer planting - Plant leaf number at harvest (2012). No interaction occured between salt concentration and cultivar for final plant leaf number at harvest (Table 4). Although salt concentration significantly affected the final plant leaf number at harvest the cultivars ‘Grand Nain’ and ‘Paz’ did not respond differently to salinity stress, as ‘Grand Nain’ scored a final number of 6.3 leaves compared to ‘Paz’ at 6.25 leaves (Table 4).

Winter planting - Plant leaf number at harvest (2013). Similar results were obtained on plant leaf number at harvest as no interaction was recorded between salt concentration and cultivar for final plant leaf number at harvest (Table 4). Increasing salt concentration significantly reduced the final plant leaf number at harvest (Table 4). However the two different cultivars where not differently affected by the salinity conditions as comparative number of leaves was counted at harvest with ‘Grand Nain’ reporting a final plant leaf number of 9.9 leaves, whilst ‘Paz’ scored 10.9 leaves on average (Table 4). Again, leaf production was favoured in the winter planting compared to the summer planting, where in the latter environmental and soil-based stress conditions is expected to exceed that of the winter planting.

Fresh shoot weight. No interaction was recorded between salt concentration and cultivar for the fresh shoot weight at termination for both the summer and winter planting (Figs. 5, 6). Both cultivars responded similarly on exposure to increasing salt concentration, this again indicating the absence of cultivar differences towards salt tolerance (Figs. 5A, 6A). In lettuce, research done in Oman by Al-Maskri et al. (2010) is was reported that fresh and dry weights of both shoots and roots was negatively affected when the salinity level was increased from 0 to 50 and 100 mM of NaCl in the irrigation water.

Cultivar ‘Grand Nain’ and ‘Paz’ did not differ in their ability to accumulate fresh shoot weight, in either the winter of summer planting. ‘Nain’ scored a fresh shoot weight at termination of 26.13g, with ‘Paz’ at 23.69g for the summer planting (Fig. 5B), while for the winter planting, ‘Paz’ score a fresh shoot weight of 53.6g compared to the 48.58g that was accumulated by ‘Grand Nain’ (Fig. 6B).

Fresh root weight. An interaction was only recorded between the salt concentration and cultivar for the summer planting, but not the winter planting, for the parameter fresh root weight at termination (Figs. 7, 8). It is evident that increasing salt concentration is detrimental for root development and weight accumulation, particularly so in the summer planting, where higher temperatures and salt concentrations were prevalent. For the summer planting, at the lower concentration range of 1 mg.L^{-1} NaCl affected 'Paz' more severely than 'Grain Nain', however in the higher salt concentration ranges the impact of salinity was comparable between cultivars (Fig. 8A). This difference in sensitivity towards salinity in the lower salt concentration range between cultivars were not observed in the summer planting (Fig. 8A).

Dry shoot weight. As observed for the parameter fresh shoot weight, there was also no interaction between salt concentration and cultivar for dry shoot weight as was recorded 30 days after termination of the trial in the winter planting (Fig. 9). Increased salt concentration negatively affected both cultivars with no significant difference that could be detected between cultivars (Fig. 9A). In Sri Lanka, on selected rice cultivars, Puvanitha and Mahindran (2017) reported that when rice was planted in saline soil of 6.6 dS.m^{-1} a negative significant effect was obvious with respect to the ability to accumulate dry shoot and root weight in exposed plants, when compared to the normal soil salinity level with an EC of 1. 8dS.m^{-1}.

Dry root weight. No interaction was shown between the salt concentration and cultivar for dry root weight as determined 30 days following harvest for the winter planting (Fig. 10). As was observed with fresh root weight, a decline with increasing salt concentration was reported for both cultivars in dry root weight (Fig. 10A), with the higher salt concentrations (2.5-4 mg.L^{-1}) being more detrimentally than lower concentration levels.

Conclusion

No significant differences in salt tolerance between 'Paz' and 'Grand Nain' could be established in this study. Therefore, no particular cultivar with a clear superior salinity tolerance ability has been identified as being more suitable for production in Jordan than the other, as both cultivars evaluated displayed similar vigour under moderate to high saline conditions. More research is therefore required to determine whether cultivar difference may emerge later during plant growth and development, to particularly assess any possible difference in yield.. In addition, the ability of likely planted banana cultivars of the Jordan Valley, including 'Paz' and 'Grand Nain', to respond to soil and foliar applied ameliorants to improve salt tolerance should investigated.

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Tables and Figures

Table 1. The physical and chemical properties of native Jordan Valley soil samples as was used as planting medium in a trial which assessed the tolerance of two banana varieties, 'Grand Nain' and 'Paz' to salinity.

Potting Soil Characteristic	pH[w]	EC[x]	%N	P ($mg.L^{-1}$)	K ($mg.L^{-1}$)	% $CaCO_3$	Exch. Ca[y]	Na %[z]	Cl ($mg.L^{-1}$)
	7.90	2.30	0.30	17.70	219.50	30.00	0.04	6.10	110.00

[w] paste extract;
[x] Electrical Conductivity as $dS.m^{-1}$, paste extract;
[y] $meq.100\ g^{-1}$;
[z] ESP % (Exchangeable Sodium Percentage)

Table 2. The fertigation solution nutrient composition per 1000 L as was used in a study which assessed the tolerance of the two banana varieties, 'Grand Nain' and 'Paz' to salinity.

Concentration	MAP	$CaNO_3$	KNO_3	K_2SO_4	$MgSO_4$	Cu EDTA	Fe EDDHA	Zn EDTA	Mn EDTA	B_2O_3	NaMo
$g.1000\ L^{-1}$	270.00	291.70	217.00	448.00	461.50	0.50	8.50	1.20	1.20	1.00	0.05

MAP: Mono-ammonium Phosphate; KNO3: Potassium Nitrate; AN: Ammonium Nitrate; $MgSO_4$: Magnesium Sulphate; B_2O_3: Boric acid; NaMo: Sodium Molybdate; $CaNO_3$: Calcium Nitrate

Table 3. Plant height (cm) at termination for both summer and winter planting for two banana cultivars ‘Grand Nain’ and ‘Paz’ when cultivated in the Jordan Valley, under saline solutions when NaCl at 1, 2, 3, 4 and 5 g.L^{-1} respectively in the summer planting and 1, 1.75, 2.5, 3.25 and 4 g.L^{-1} for the winter planting was added to a standard fertigation solution.

Salt concentration (g.L^{-1}) Summer/ Winter planting	Summer planting (cm)	Winter planting (cm)
1 / 1	14.5a^{z}	26a
2 / 1.75	11.4b	20.3b
3 / 2.5	7.9c	17.5c
4 / 3.25	7.4c	15.2d
5 / 4	5.6d	14.3d
Cultivar		
‘Grand Nain’	9.5a	19a
‘Paz’	9.3a	18.9a
Summer planting	F value	p-value
Salt concentration	**63.15**	**0.0000**^{y}
Cultivar	0.425	0.5150
Salt concentration * Cultivar	0.570	0.6844
Winter planting		
Salt concentration	**81.942**	**0.0000**
Cultivar	0.070	0.7912
Salt concentration * Cultivar	1.070	0.3729

[z] Values within columns with different letters are statistically different at the 95% confidence level.

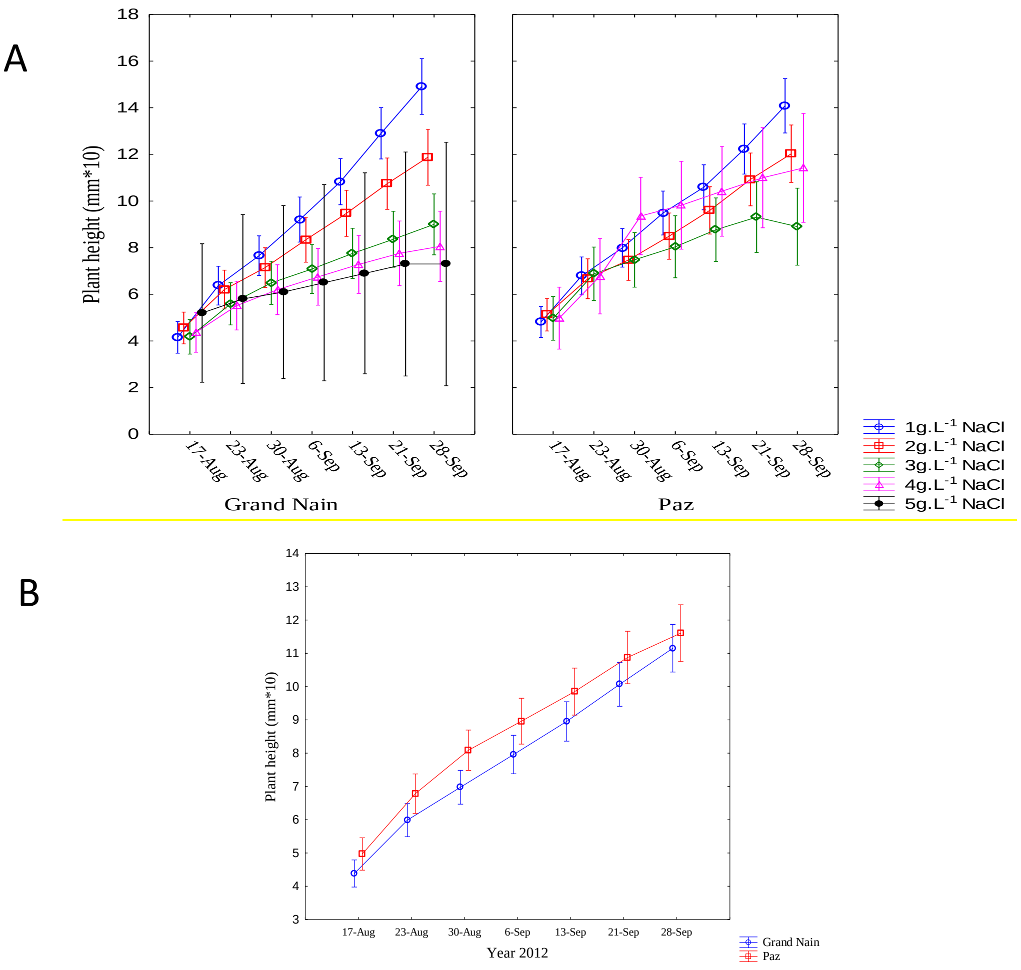
[y] p-values in printed in bold is significant at the 5% confidence level

Table 4. Plant leaf number at termination for both summer and winter planting for two banana cultivars 'Grand Nain' and 'Paz' when cultivated in the Jordan Valley, under saline solutions when NaCl at 1, 2, 3, 4 and 5g.L^{-1} for the summer planting and 1, 1.75, 2.5, 3.25 and 4 g.L^{-1} for the winter planting respectively was added to a standard fertigation solution.

Salt concentration (g.L^{-1}) Summer/ Winter plantings	Summer planting	Winter planting
1 / 1	7.5a [z]	11.7a
2 / 1.75	6.9ab	10.2b
3 / 2.5	6.2cb	9.6bc
4 /3.25	5.8cd	9.9bc
5 –4	5.0d	8.4c
Cultivar		
'Grand Nain'	6.3a	9.9a
'Paz'	6.3a	10.9a
Summer planting	F value	p-value
Salt concentration	16.881	0.0000
Cultivar	0.017	0.8965
Salt concentration * Cultivar	0.735	0.5692
Winter planting		
Salt concentration	**11.673**	**0.0000** [y]
Cultivar	0.183	0.6689
Salt concentration * Cultivar	1.718	0.1479

[z] Values within columns with different letters are statistically different at the 95% confidence level.

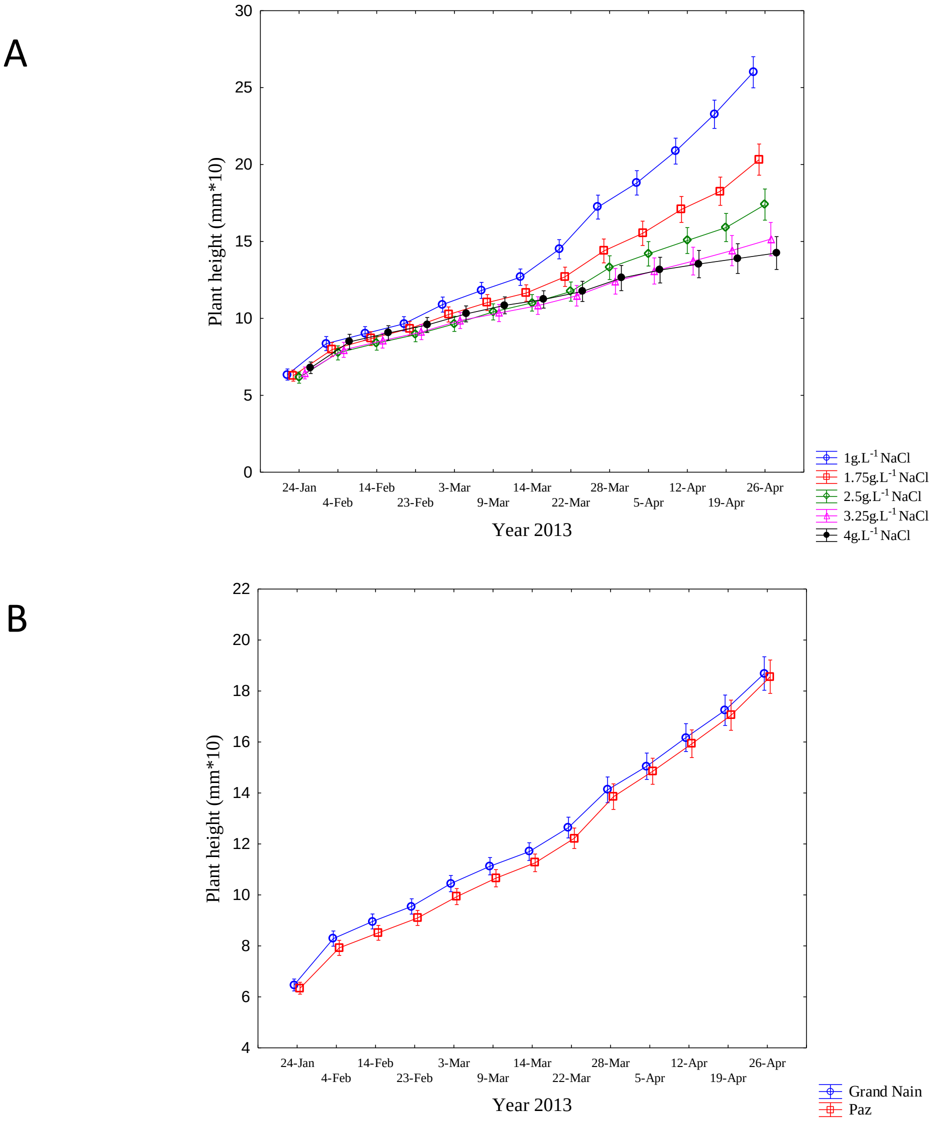
[y] p-values in printed in bold is significant at the 5% confidence level



Plant height (mm*10)	F Value	Pr>F
Intercept	1597.86	0.0000
Salt Concentration	5.66	0.0012
Cultivar	3.75	0.0554
Salt Concentration*Variety	0.99	0.4026
Time	635.19	0.0000
Time*Salt Concentration	29.98	0.0000
Time * Cultivar	1.52	0.1680
Time*Salt Concentration*Cultivar	**2.57**	**0.0004**[y]

[y] p-values in printed in bold is significant at the 5% confidence level

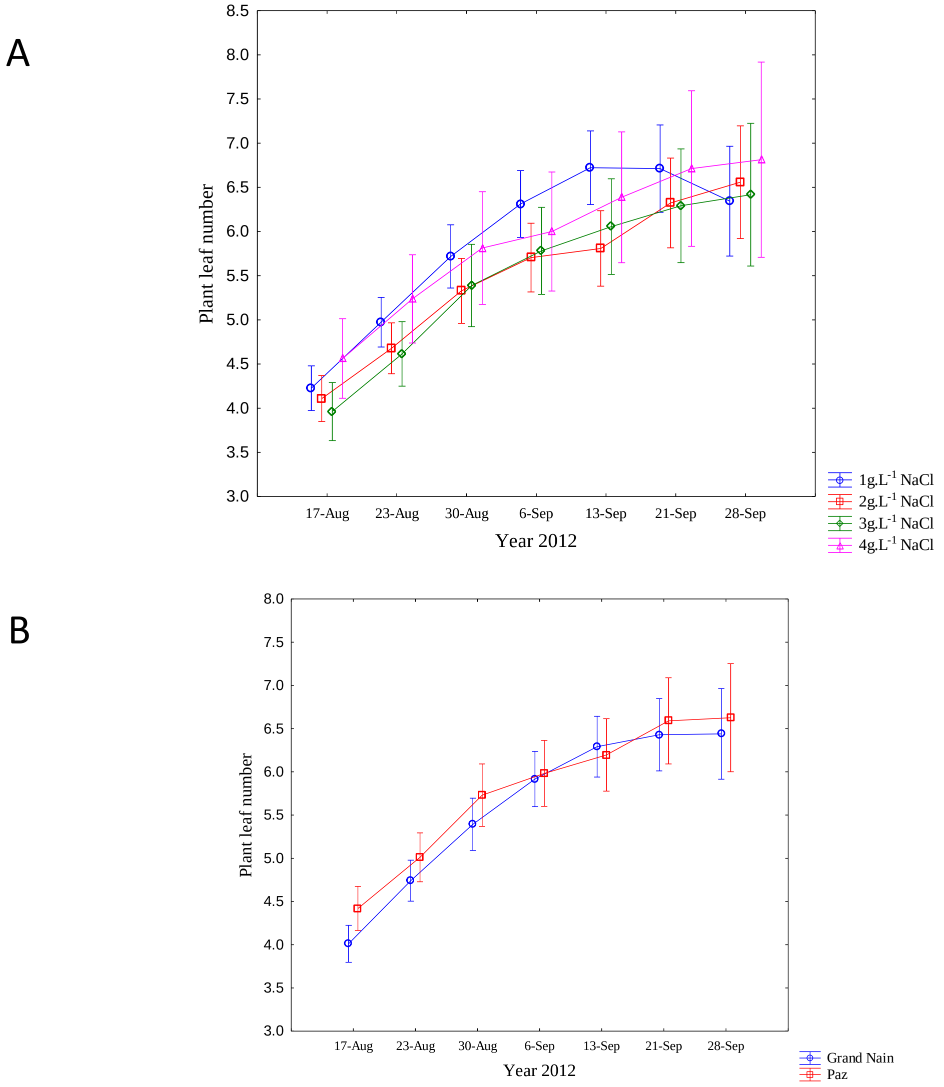
Fig. 1. Plant height weekly development (mm x10) of two banana cultivars ‘Grand Nain’ and ‘Paz’ (B) as recorded over a six-week period, from 11 August to 2 October 2012, during a summer planting whilst being subjected to the same fertilizer blend, but at increasing salinity (A) as induced by NaCl at 1, 2, 3, 4 and 5 g.L^{-1}. Missing plots for ‘Paz’ due to the high mortality rate of plants at 5 g.L^{-1} did not allow for this concentration level to be incuded in the data analysis.



Source of variance Plant height (mm*10)	F Value	Pr>F
Intercept	8129.78	0.0000
Salt Ccncentration	24.01	0.0000
Cultivar	1.47	0.2273
Salt Concentration*Cultivar	0.98	0.4209
Time	2297.96	0.0000
Time*Salt concentration	**84.90**	**0.0000**^{z}
Time * Cultivar	0.79	0.6582
Time*Salt concentration*Cultivar	0.98	0.5211

^{z}p-values in printed in bold is significant at the 5% confidence level

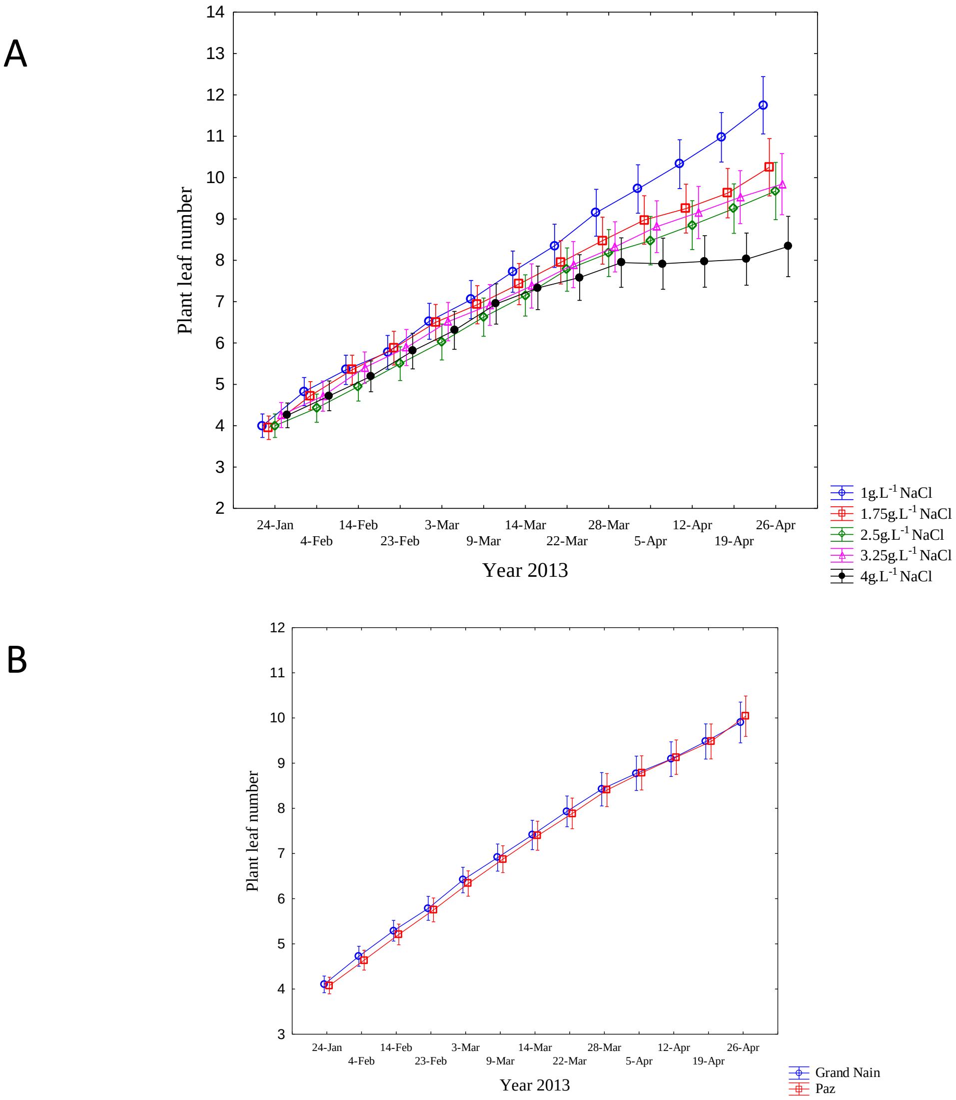
Fig. 2. Plant height weekly development (mm x10) of two banana cultivars 'Grand Nain' and 'Paz' (B) as recorded over a six-week period from 18 January to 25 April 2013 during a winter planting when subjected to the same fertilizer blend, but at increasing salinity (A) as induced by NaCl at 1, 1.75, 2.5, 3.25 and 4 g.L^{-1}.



Source of variance Plant leaf number	F Value	Pr>F
Intercept	3699.46	0.0000
Salt concentration	1.65	0.1813
Cultivar	1.03	0.3113
Salt concentration*Cultivar	0.22	0.8830
Time	**63.60**	**0.0000**^{z}
Time*Salt concentration	0.85	0.6448
Time * Cultivar	0.60	0.7307
Time*Salt concentration*Cultivar	1.22	0.2389

^{z}p-values in printed in bold is significant at the 5% confidence level

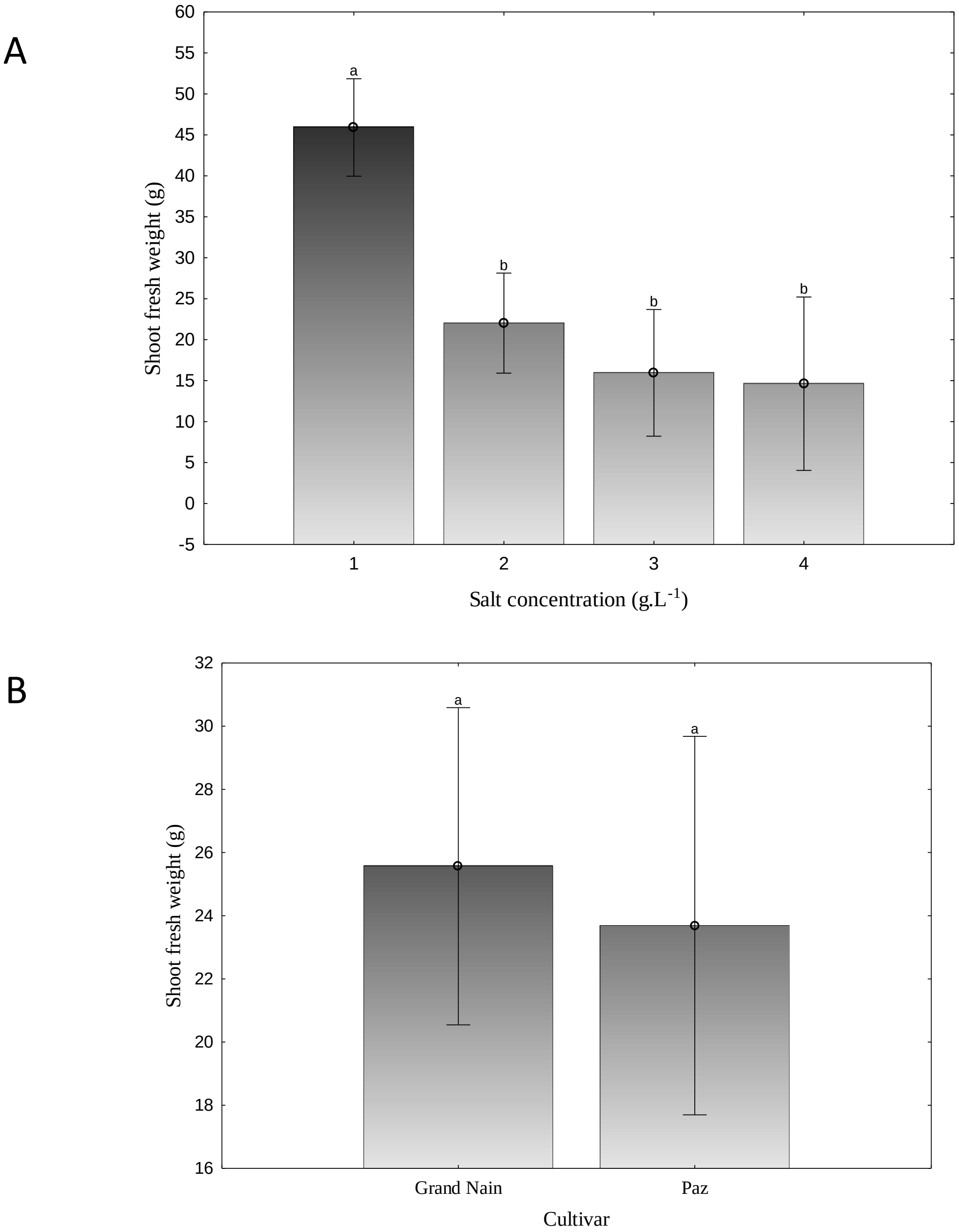
Fig. 3. Plant leaf number weekly development of two banana cultivars ‘Grand Nain’ and ‘Paz’ (B) when subjected to the same fertilizer blend, but at increasing salinity (A) as induced by NaCl at 1, 2, 3, 4 and 5 g.L^{-1} as recorded over a six-week period from 11 August to 2 October 2012 during a summer planting.



Source of variance Plant leaf number	F Value	Pr>F
Intercept	5139.01	0.000000
Salt concentration	2.96	0.0213
Cultivar	0.01	0.9293
Salt concentration*Cultivar	1.06	0.3762
Time	1001.70	0.000000
Time*Salt concentration	**10.73**	**0.000000**^{z}
Time * Cultvar	0.25	0.9958^{y}
Time*Salt concentration*Cultivar	1.30	0.0838

^{z}p-values in printed in bold is significant at the 5% confidence level

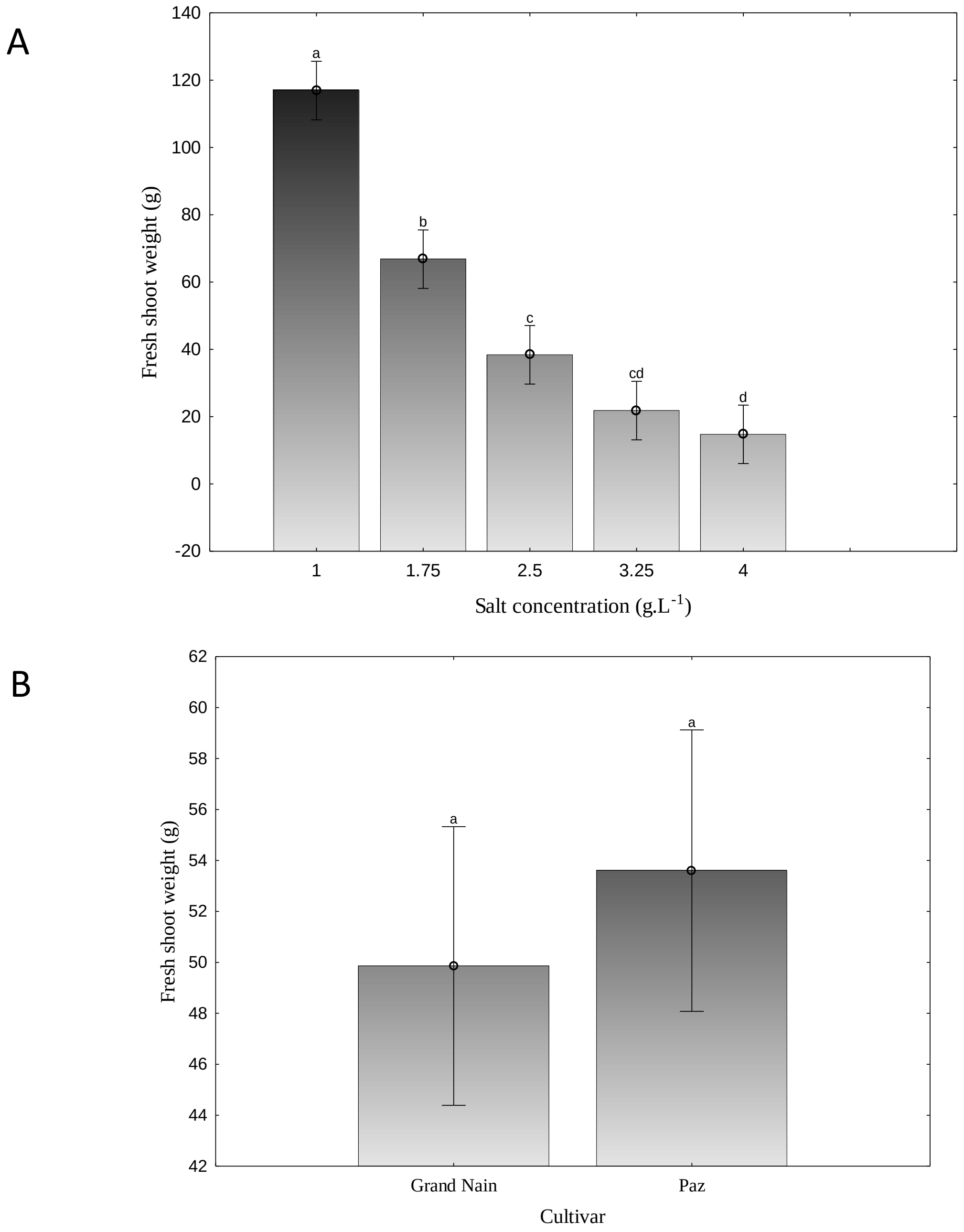
Fig. 4. Plant leaf number weekly development of two banana cultivars 'Grand Nain' and 'Paz' (B) when subjected to the same fertilizer blend, but at increasing salinity (A) as induced by NaCl at 1, 1.75, 2.5, 3.25 and 4g.L^{-1} as recorded over a six-week period from 18 January to 25 April 2013 during a winter planting.



Source of variance Shoot fresh weight	F Value	Pr>F
Salt concentration	**13.3887**	**<.0001**^{z}
Cultivar	0.2269	0.6347
Salt concentration * Cultivar	1.1906	0.3169

^{z}p-values in printed in bold is significant at the 5% confidence level

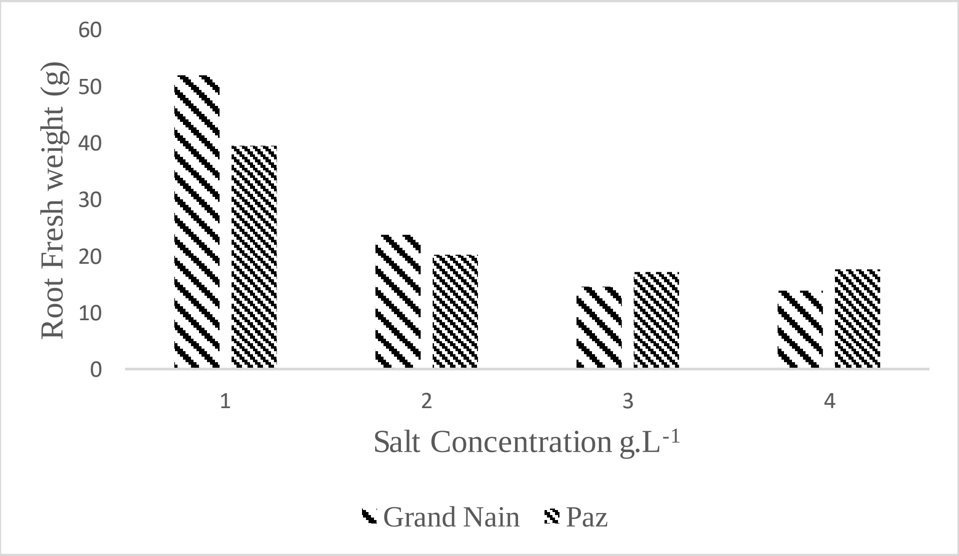
Fig. 5. Shoot fresh weight (g) of two banana cultivars ‘Grand Nain’ and ‘Paz’(B) when subjected to the same fertilizer blend, but at increasing salinity (A) as induced by NaCl at 1, 2, 3, 4 and 5 g.L^{-1} as determined on 2 October 2012 at the day of termination of the summer planting.



Source of variance Shoot fresh weight	F Value	Pr>F
Salt concentration	**89.1221**	**<.0001**[z]
Cultivar	0.9025	0.3433
Salt concentration * Cultivar	2.2765	0.0625

[z] p-values in printed in bold is significant at the 5% confidence level

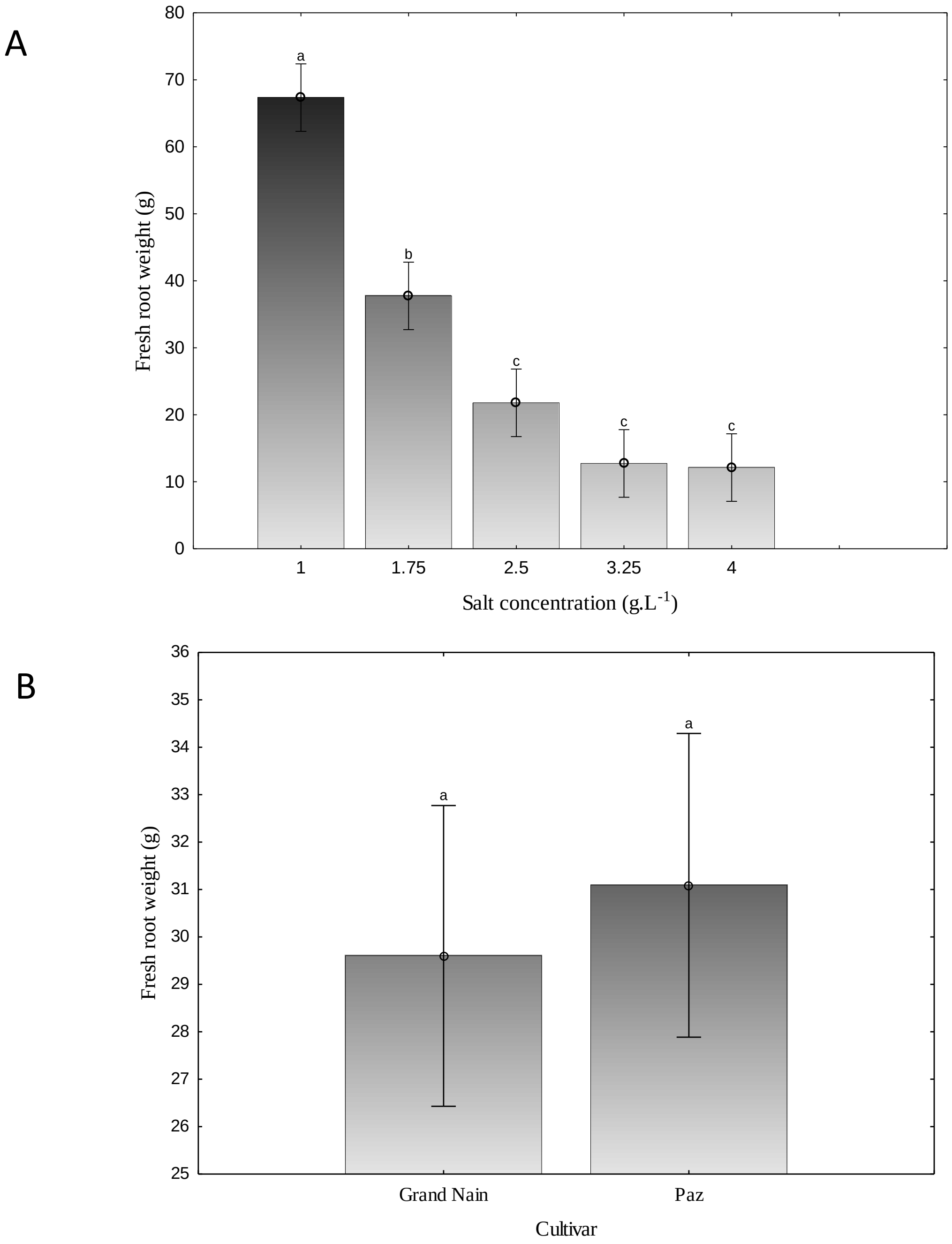
Fig. 6. Fresh shoot weight (g) of two banana cultivars ‘Grand Nain’, and ‘Paz’ (B) when subjected to the same fertilizer blend, but at increasing salinity (A) as induced by NaCl at 1, 1.75, 2.5, 3.25 and 4 g.L^{-1} as determined on 25 April 2013 at the termination day of the winter planting.



Source of variance Root fresh weight	F Value	Pr>F
Block	1.33	0.1867
Salt concentration	16.73	<.0001
Cultivar	1.09	0.2989
Salt concentration * Cultivar	**3.45**	**0.0201**[z]

[z]p-values in printed in bold is significant at the 5% confidence level

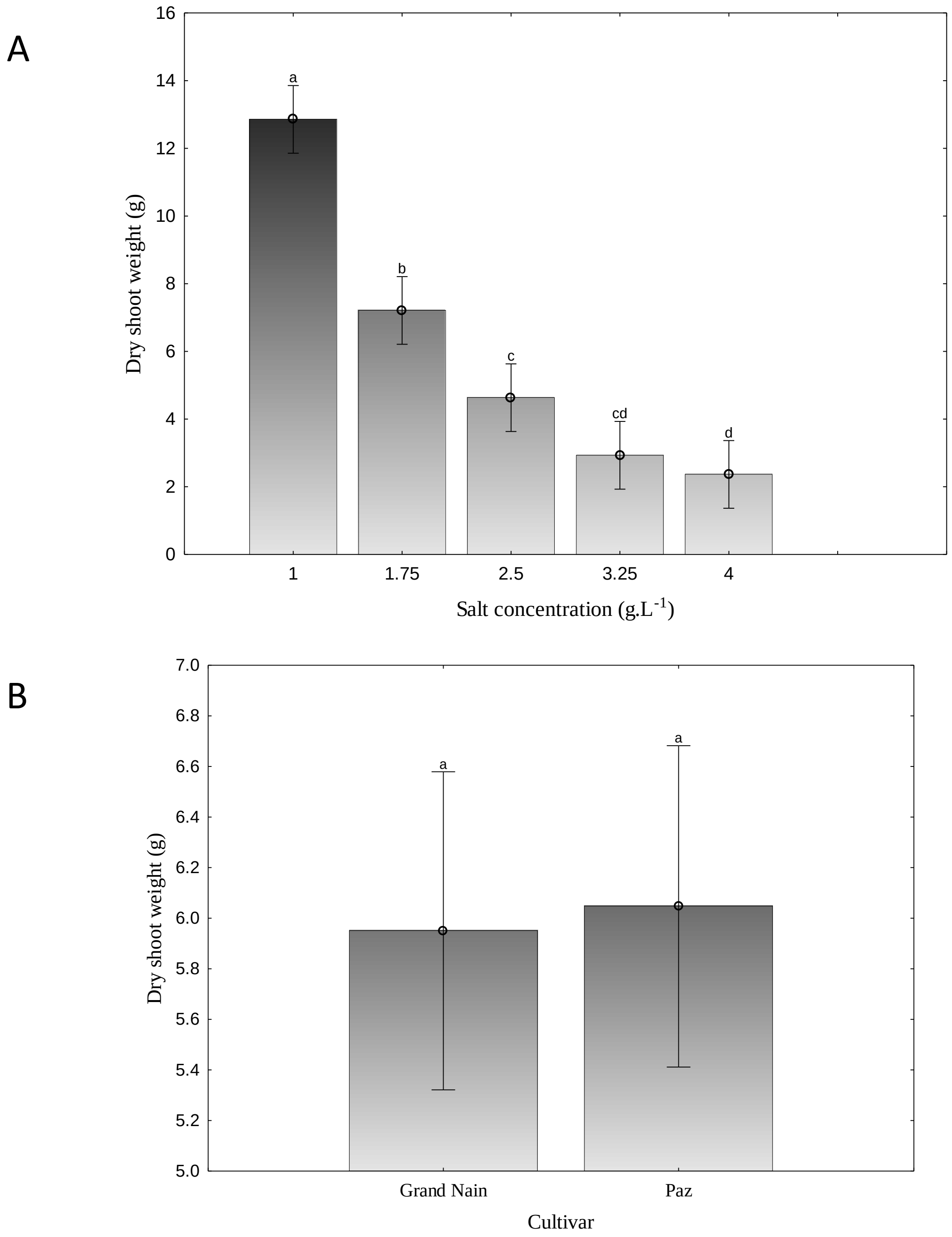
Fig. 7. Root fresh weight (g) of two banana cultivars ‘Grand Nain’ and ‘Paz’ (B) when subjected to the same fertilizer blend, but at increasing salinity (A) as induced by NaCl at 1, 2, 3, 4 and 5 g.L^{-1} as determined on 2 October 2012 at the day of termination of the summer planting.



Source of variance Fresh root weight	F Value	Pr>F
Salt concentration	**81.9800**	**<.0001**[z]
Cultivar	0.4246	0.5154
Salt concentration *Cultivar	1.0581	0.3786

[z] p-values in printed in bold is significant at the 5% confidence level

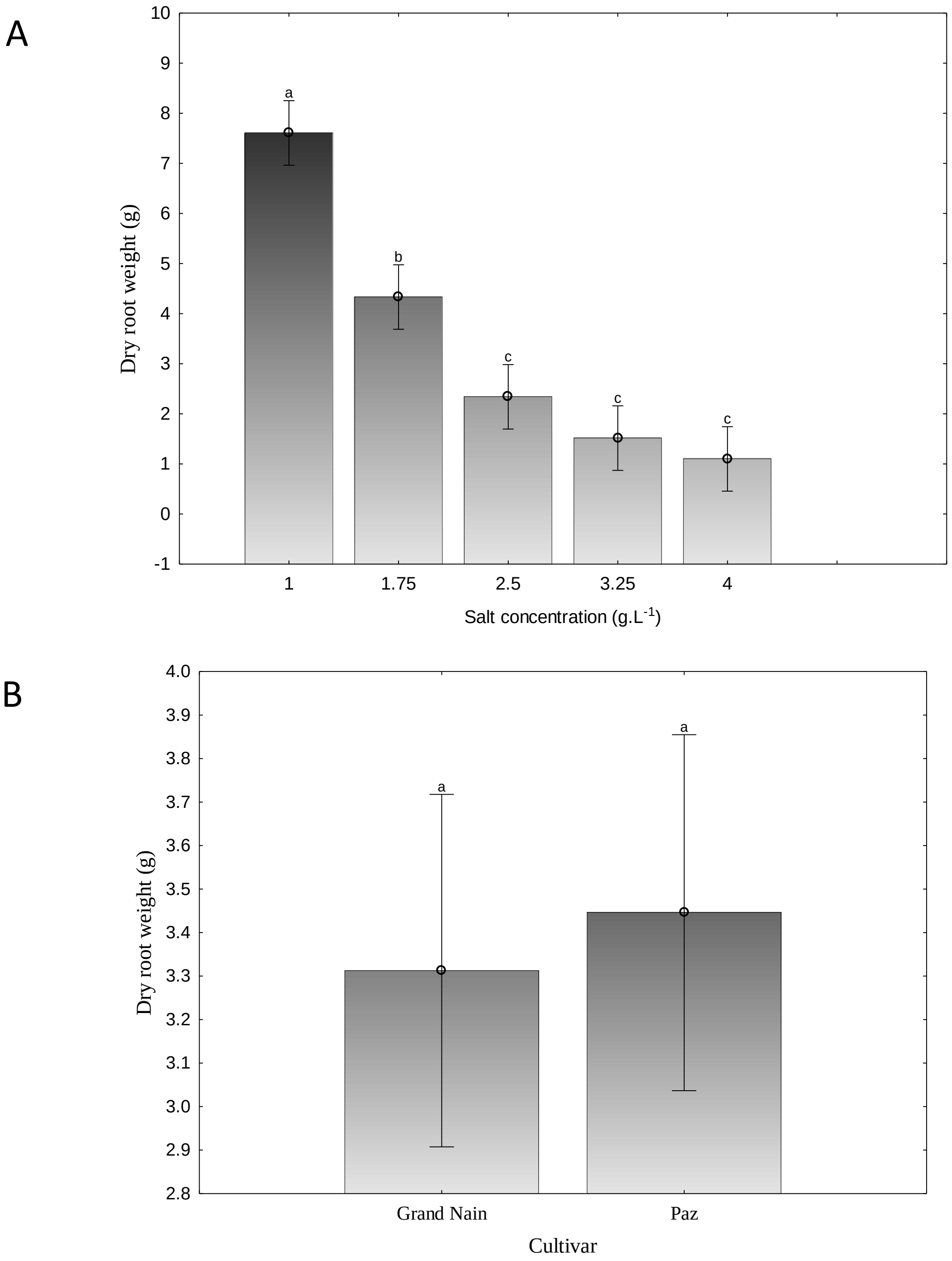
Fig. 8. Fresh root weight (g) of two banana cultivars ‘Grand Nain’, and ‘Paz’ (B) when subjected to the same fertilizer blend, but at increasing salinity (A) as induced by NaCl at 1, 1.75, 2.5, 3.25 and 4 g.L^{-1} as determined on 25 April 2013 at the termination day of the winter planting.



Source of variance Dry shoot weight	F Value	Pr>F
Salt concentration	**71.0625**	**<.0001**^{z}
Cultivar	0.0454	0.8314
Salt concentration *Cultivar	0.3164	0.8358

^{z}p-values in printed in bold is significant at the 5% confidence level

Fig. 9. Dry shoot weight (g) of two banana cultivars ‘Grand Nain’, and ‘Paz’ (B) when subjected to the same fertilizer blend, but at increasing salinity (A) as induced by NaCl at 1, 1.75, 2.5, 3.25 and 4 g.L^{-1} as determined on 26 May 2013, one month after the termination day of the winter planting.



Source of variance

Dry root weight	F Value	Pr>F
Salt concentration	**66.9821**	**<.0001**[z]
Cultivar	0.2086	0.6484
Salt concentration * Cultivar	1.5741	0.1828

[z] p-values in printed in bold is significant at the 5% confidence level

Fig. 10. Dry root weight (g) of two banana cultivars 'Grand Nain' and 'Paz' (B) when subjected to the same fertilizer blend, but at increasing salinity (A) as induced by NaCl at 1, 1.75, 2.5, 3.25 and 4 g.L^{-1} as determined on 26 May 2013, one month after the termination day of the winter planting.

Paper 4: The Efficacy of Biostimulants to Ameliorate the Impact of Salinity on Two Determinate Tomato Cultivars Grown in the Jordan Valley

ABSTRACT

Five biostimulants (compost, bacteria, glycine betaine, kelp and sulphuric acid) were assessed for their efficacy to enhance the growth and production of the two determinate tomato cultivars, 'Ayah' and 'Bahjah', when cultivated under production conditions of salinity, typical to that experienced in the Jordan valley. The compost, bacteria, kelp and sulphuric acid treatments were soil applied, while the glycine betaine was a foliar application. Trials were carried out from 13 October 2013 to 25 January 2014. Salinity was induced by the addition of 3 g.L^{-1} NaCl to the standard daily applied fertigation composition to achieve an electrical conductivity (EC) of 6.4 - 6.6 dS. L^{-1}. Various growth parameters were selected to assess the crop response to salinity. Changes in plant height and leaf number was recorded over time, whilst fresh and dry root- and shoot weight, the number of fruit, fruit weight, the largest leaf width as indication of leaf area, as well as shoot weight were recorded at harvest. Results indicated that the compost treatment was the best soil ameliorant to sustain tomato production under saline conditions. The kelp-, sulphuric acid- and bacteria treatments generally had a beneficial effect on roots, whereas glycine betaine promoted vegetative growth above ground, while also impacting positively on dry root weight. When the bacteria was used in combination with compost, the amelioration effect of the compost was reduced compared to when compost only was used. 'Ayah' proved consistently more tolerant to salinity than 'Bahjah'. Compost is recommended as a soil ameliorant to reduce soil salinity for tomato cultivated under similar growing conditions than this study. Further research is required to investigate combinations of ameliorants to enhance the performance of compost through increasing resilience of tomatoes to overcome the limitations of salinity experienced as a worldwide challenge.

ADDITIONAL INDEX WORDS.

Abiotic stress, 'Ayah', ***Bacillus subtilis,*** **'Bahjah', compost, glycine betaine, kelp, sulphuric acid**

Introduction

High quality food production in arid and semi-arid regions of the world faces serious challenges as it is largely dependent on irrigation, due to historically low rainfall conditions or as result of a declining rainfall trend, an aspect that has become especially relevant over the last decades (Nicholson and Selato, 2000). It is required for such agricultural systems under severe environmental pressures to at least maintain their current crop productivity in order to meet the demand imposed by an ever-increasing population. This challenge is exasperated as producers have to cope with a continuous decline in water quality available for irrigation, in addition to the natural occurring saline and sodic soils (Del Amor et al., 2001). Finding sustainable, effective solutions for salinity is thus becoming increasingly critical as irrigated agriculture contributes well over 30 % of the total agricultural production (Hillel, 2000).

Salinity limits the productivity of crops as a direct effect of ion toxicity (Al-Karaki, 2000), together with adverse osmotic effects, which results in physiological, morphological and biochemical stresses (Ashraf and Fooland, 2007). These cellular and metabolic modifications over time result in lower photosynthesis, growth inhibition, a range of nutritional deficiencies, the inhibition of protein synthesis and in due course crop yield reduction.

Many, if not all crops, including tomato (Juan et al., 2005), have been reported to be negatively affected by salinity to varying degrees, even though some tomato cultivars are often reported to be moderate saline tolerant (Reina-Sanchez et al., 2005). Salinity tolerance in tomato varieties was defined by Juan et al. (2005), amongst others, as the ability to adapt to salinity by exhibiting a reduced uptake and accumulation of toxic ions in leaves. When ten tomato varieties were evaluated in their study, ‘Jaguar’ and ‘Brilliant’ was reported to be most tolerant to salt stress.

Tomato is listed the most important vegetable crop world-wide, with a global production of around 233.46 million metric tons (MT), which in the last ten years alone increased with about 48 % (FAOSTAT Database, 2014). In Jordan, tomato is considered the leading vegetable crop, both for local consumption and export, as it represents 27.5 % of the total area under vegetable production (Jordan Ministry of Agriculture, 2012), with an estimated yield of 837 MT in 2016 (FAOSTAT Database, 2016). Tomato producers in Jordan is located either in the Highlands or Jordan Valley, with the latter contributing approximately 60 % of the cultivation area (Ammari et al., 2013). Climatic regions in Jordan are extremely diverse (Abandah, 1978). Elevations may differ from 400 m below sea level in the Jordan Valley to 1500m above sea level, in addition to variations in planting dates, rainfall and cultural practices, all contributing to variation in the possible production environment. The occurrence of various soils types and their physical and chemical classifications further contribute to the variation that influence production factors and that are typical challenges faced by producers with Jordan (Jaradat, 1991). However, there is one, dominant common factor across production areas: all farmers in Jordan are forced to use saline water sources for irrigation, due to the absence of adequate supplies of non-saline water (Abu-Khadejeh et al., 2012). Various efforts have applied to overcome this overarching problem, such as to screen a large number of new varieties of various crops for their productivity under saline conditions (Mohammed et al., 1998), as well as evaluating the suitability and cost effectiveness of hydroponic systems (Shibli, 1993). Recently, soil ameliorants and other biotic products were suggested as a solution to overcome abiotic crop stress that may result from drought and/or salinity.

A practice which increased in popularity over the last two decades, internationally and on numerous crops, is the addition of organic matter conditioners like manure and compost to improve salt-affected soils (Melero et al., 2007). A study on rice in Thailand (Cha-um et al., 2006) reported that application of gypsum and farmyard manure to saline fields was an effective remediation for reducing plant stress and its associated disorders caused by contaminating salts. A study conducted in the coastal areas of northern China reported that a combination of green waste compost, sedge peat (composted leaf mould made from the leaves and stalks of sedge plants, which is a type of grassy Marsh/Bog plant) and furfural residue (an organic compound made by the dehydration of sugars of barley,oats and other forages), rather than the amendments alone, had substantial potential for ameliorating saline soils (Wang et al., 2014). Similar, Lakhdar et al. (2009) concluded that the use of composted municipal solid waste in Tunis could both enhance soil productivity in agricultural fields by improving fertility and by serving as an alternative to alleviate the adverse effects caused by soil salinization. In this study, low cost soil recovery was achieved through a combination of high organic matter content and low concentrations of inorganic and organic pollutants, which allowed for an improvement of the physical, chemical and biochemical soil characteristics.

Drought and salinity as stress factors of the plant andare closely linked by common mechanisms (Taiz et al., 2015). In Australia Nguyen et al. (2012) conducted a study on the effect of compost on water availability in tomato during drought and subsequent recovery. They reported that, with sufficient water supply, the rates of photosynthesis and transpiration were comparable in all treatments. However, drought stressed plants with incorporated compost (with the compost incorporated with the soil particles) wilted earlier than control plants, whereas mulched compost (with the compost only mulched on the soil surface) increased water availability to plants and thus could effectively extended the number of days until wilting. Nevertheless, both the earlier wilting and the rapid recovery after drought of plants associated with the incorporated compost treatment, was ascribed to their increased root length development.

Another consideration towards salinity amelioration is the addition of *Bacillus subtilis* bacteria. In a study conducted in China on white clover, Han et al. (2014) reported that plants grown in saline soil, but inoculated with the *B. subtilis* GB03 type bacteria, had significantly higher production indicators in terms of shoot height, root length, plant biomass, leaf area and chlorophyll content than those grown in non-inoculated, saline soils. The *Bacillus* inoculation, in addition to enhancing production, also resulted in a decrease in shoot and root sodium (Na) content along with an increase in the nitrogen:potassium (N:P) ratio. Mohamed and Gomaa (2012) demonstrated a significant increase in the fresh- and dry weight of roots and leaves when radish seeds were first inoculated with *B. subtilis* before planting. Also, an increase in the phytohormones gibberellic acid (GA_3) and the auxin, indole acetic acid (IAA), along with a higher nitrogen (N), phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg) content was recorded. These changes occurred simultaneously with a decrease in abscisic acid (ABA), Na and chlorine (Cl) content. Further confirmation for the role of *B. subtilis* in combination with mycorrhizal fungi was obtained from the study of Abdel-Rahman et al. (2011) which concluded that inoculation of sweet basil cultivars successfully induced tolerance to salinity.

Glycine betaine, a fully N-methyl-substituted derivative of glycine, is a metabolite often associated with crops adapted to saline and/or arid areas (Rhodes and Hanson, 1993). Glycine betaine is furthermore reported to accumulate in plants such as *Arabidopsis*, maize and tomato (Chen and Murata, 2008) as a response to drought and salinity. Holmstrom et al. (2000) reported that the expression of glycine betaine in tobacco was associated with an increase in abiotic stress tolerance, particularly by offering protection to the photosynthetic apparatus. Hu et al. (2012) found that application of exogenous glycine betaine on perennial rye grass enhanced the salt tolerance by increasing the K^+ and chlorophyll levels, whilst decreasing the Na^+ content. Similarly, Hamdia and Shaddad (2010) reported exogenous glycine betaine applications to contribute to the improvement of plant salt tolerance through its role in the Na^+/K^+ discrimination under salinity conditions. Rezaei et al. (2012) explored the effect of applied glycine betaine on tomato under drought stress conditions, which had similar physiological effects on plants than when being exposed to soil salinity stress. Glycine betaine was applied by means of foliar sprays at 0, 5 and 10 mM respectively, at 10 day intervals. A 10 mM concentration of glycine betaine increased the vegetative growth traits of shoot height, root length, leaf number and leaf area by 70 %, 73 %, 187 %, 193 % respectively, whilst the total shoot fresh weight, total shoot dry weight, relative water content and stress tolerance index increased by 168 %, 9 %, 72 % and 122 % respectively, against a control that received no treatment. Glycine betaine at a rate of 10 mM produced the best results and was recommended for alleviation of stress conditions.

Kelp products are considered as the most researched and widely used type of biostimulant (Du Jardin, 2012) and are widely associated with soil amelioration for salinity (Becket and Van Staden, 1990). In addition to the presence of mineral elements, seaweed extracts are also rich in biologically active plant growth regulators such as auxins, cytokinin and gibberellins along with considerable amounts of polyamines, abscisic acid and brassinosteroids (Lötze and Hoffman, 2016). The presence of a range of osmo-protectants such as betaine, proline, polyamines and the common storage sugar-alcohol, mannitol, have also generally been identified in kelp products (Stoop et al., 1996; Lötze and Hoffman, 2016). These osmolyte-related metabolites are proclaimed to offer stress mitigation through the mode of coenzyme regulation, free-radical scavenging and enhanced resistance to pathogens (Bohnert and Jensen, 1996; Prabhavathi and Rajam, 2007; Vera et al., 2011). Betaine and proline in kelp products are considered to act as a buffer to the plant under stress conditions, while mannitol plays an important role in osmo-regulation (Bohnert and Jensen 1996; Stoop et al., 1996).

In a study by Arthur et al. (2013), kelp extract was applied in combination with irrigation water with pH values ranging from 5, 6.5 and 8.5 and having the water hardness at either 200 mg.L^{-1} or 400 mg.L^{-1} $CaSO_4$. Kelp extracts were reported to be most effective to promote plant growth in a neutral pH range, although it also positively influenced growth over in a wider range of pH and water hardness conditions. Research conducted in Iraq compared the efficacy of sea weed extract to promote tomato seed germination in combination with salt water or drainage water as treatments. However surprisingly, seaweed extracts did not exert a significant effect when it was applied to the control seeds which received only distilled water. The positive effects of the sea weed extract were mainly observed on the percentage and rate of germination, the plumule and radicle length, along with the fresh- and dry seedling weight when the salt water and drainage water was mixed with the seaweeds extract (Alalwani et al., 2012). Elouaer et al. (2014) ascribed the ameliorating effect of kelp applications on two tomato seed varieties, produced under salt stress in Morocco, to the presence of growth hormones, nutrients and other important physio-chemical compounds.

Sulphuric acid could also be considered as a well-established and widely used soil ameliorant employed to decrease the detrimental effect of salinity in saline and sodic soils. In a study performed on wheat in Pakistan, Ramzan et al. (1989) reported that the addition of sulphuric acid, at two rates of application, was more effective against salinity compared to gypsum. Efficacy in this study was achieved by lowering the electrical conductivity along with the sodium absorption rate of the soil. Niazi et al. (2001) compared sand, gypsum and sulphuric acid for their respective efficacies to ameliorate dense, saline and sodic soils on rice. The treatment where gypsum was combined with sulphur a reduction in the sodium absorption rate resulted that was significant by the second year following treatment, with a resulting increase in the yield of rice, already visible with the first crop, while the highest reduction in pH was recorded in using gypsum alone. In another study conducted on Faba beans, Abdelhamid et al. (2013) reported that the addition of sulphur to saline soil enhanced the soil physical properties by increasing drainable pores, along with an improved water holding capacity and hydraulic conductivity of the soil. A plant mineral analysis showed an increase in N, P, K, Cl and Ca content alongside a reduction in the Na:K ratio. In accordance with above mentioned studies, a subsequent study by Sadiq et al. (2003) in Pakistan confirmed that sulphuric acid and gypsum improved the performance of six cotton varieties with respect to germination percentages and general yield under saline conditions.

Considering the importance of tomato production for the Jordan region, the aim of this study was thus to evaluate the efficacy of four commercially available soil applied biostimulant ameliorants (compost, Fulzyme™, KSC Sulphacide™ and Kelp®) and one commercial foliar applied biostimulant (GreenStim®) to improve tolerance in two widely grown, determinate tomato varieties, ‘Ayah’ and ‘Bahjah’, to moderate severe salinity stress as is typical of the natural, saline, silty-clay soils of the Jordan Valley as simulated by the control.

Materials and Methods

Plant Material. Two determinate tomato (*Solanum lycopersicum*) cultivars grown commercially in the Jordan Valley were chosen for this study. The ‘Ayah’ F1 variety is produced by Clause, USA (HM Clause Inc., 260 Cousteau Place, Suite 100, Davis, CA 95618, USA) and the ‘Bahjah’ F1 variety, by Yuksel Seeds, Turkey (Madenler Mallesi, 07300 Antalya, Turkey). Seeds were sourced from local distributers, with ‘Ayah’ obtained from the Agricultural Materials Company Ltd (Jordan Vegetables and Fruits Central Market, Al Juwaidah, Amman), whereas ‘Bahjah’ was acquired from Zizia Company for Agricultural Materials (Abdel Hamid Sharaf St., Shmeisani, Amman) in Jordan.

Seedlings were established in planting trays of 207 cells, where each cell had a 3 cm diameter and were filled with a medium comprising of 1:1 ratio of peat moss:coco peat. Trays were kept in the Modern Technical Nursery, South Shoonah (31 52` 16.85” N; 35 37` 21.35” S) to complete a germination- and hardening off period of four weeks. Thereafter, plants were transplanted on 11 October 2013, at the four to five true leaf stage, into 26 x 26 cm pots, filled with the saline, silty-clay soils of the Jordan valley as the base planting medium. Soil analysis was performed prior to planting at the Arab Centre for Engineering Studies LTD (www.aces-int.com) (Table 1). Eighty-four pots per variety were placed under a 60 % shade black netting tunnel structure for the duration of the trial. Additional plastic covering was added to exclude any precipitation during the rainy season. Temperatures at the cultivation site outside the tunnel ranged between 22 - 30˚C during the day, with 12 - 22 ˚C during the night, and a relative humidity which varied from 35 - 75 % (*www.jometeo.gov.jo*).

Nutrition. Pots were fertigated on a daily basis with a solution which contained all essential nutrients required, excluding Ca which was added separately. The selected fertilizer blend is representative of that routinely used by tomato producers of the Jordan Valley and neighbouring countries. Nutrient ratios were as follow: N: 1.7; P: 0.38; K: 2.15; Ca: 0.75; Mg: 0.45; S: 0.6 and trace elements (a mixture of iron (Fe), zinc (Zn), manganese (Mn), copper (Cu), boron (B) and molybdenum (Mo)) which collectively contributed a ratio of 0.01 in relation to the macro-nutrients. Each tank per contained 560 g potassium nitrate (KNO_3), 137 g mono-ammonium phosphate (MAP), 44.5 g ammonium nitrate (AN), 246 g magnesium sulphate ($MgSO_4$), 0.5 g Cu (Cu chelated on EDTA), 8 g Fe (Fe chelated on EDDHA), 1.2 g Mn (Mn chelated on EDTA), 1.2 g Zn (Zn chelated on EDTA), 1g Boric acid (B_2O_3) and 0.05 g sodium molybdate (Na_2MoO_4) per 1000 L respectively.

Finally, NaCl at 3 $g.L^{-1}$ was added to the solution mix to achieve an electrical conductivity (EC) of 6.4 - 6.6 $dS.L^{-1}$ in the first four tanks which were sufficient to supply nutrients up to the phenological stage of flowering. At this stage, the EC was lowered to 4.3 $mS.L^{-1}$, where after this EC was maintained between 4.1 to 4.5 $mS.L^{-1}$, using 2.1 $g.L^{-1}$ NaCl for Tanks 5 to 9. The 168 pots used in the trial required approximately 1000 L for fertigation over an eight to eleven day period, so that a total of nine tanks were used over the entire experimental period. The blend in the tanks was agitated with a suitable mixer on a weekly basis to ensure homogeneity of the solution (Table 2). An additional tank which contained only calcium nitrate ($CaNO_3$) at 437.5 $g.1000L^{-1}$ was used in combination with the fertilizer blend (Table 2).

Daily fertigation occurred from the standard mixture tanks, except for once a week (on Fridays), when only $CaNO_3$ was provided. Fertigation rates were set to ensure a 20 % runoff per pot after the first 30 minutes following fertigation for the purpose of leaching extra salts (a usual practice of farmers in saline soils). At the start of the experiment, this runoff percentage was achieved at a fertigation rate of 1000 ml of solution per pot, but from 8 November 2013, the fertigation volume was reduced to 800 ml per pot due to a lower demand, based on lower daily temperatures and the resulting reduced evapotranspiration. The EC, pH and temperature of each tank were recorded one hour after mixing (Table 3). The pH of the potting media was recorded on 7 and 21 November 2013 as a range of between 6.2 and 6.8.

Treatments. The trial comprised seven treatments as summarised in Table 4. The Control treatment consisted of regular saline, silty-clay soils from the Jordan Valley as the entire potting medium. The second treatment (Compost) included the use of regular saline, silty-clay Jordan Valley soils prepared in a 1:3 ratio with compost as a planting media (Cocco peat: Blumenerde, Floragard, ratio 1:1, D-26135 Oldenburg, Germany) (Table 5). A third treatment (Bacteria) used similar soils than that of the Control treatment, but for this treatment the soil was mixed with 1g of a *Bacillus subtilis*-based Fulzyme^{TM} product (JH BIOTECH, INC. P.O. Box 3538, Ventura, CA 93006, www.jhbiotech.com) per pot (Table 5). The fourth treatment (Glycine betaine) used regular Jordan Valley soil as a planting media, but in combination with GreenStim® (Lallemand, Ul. Bruzdowa 98B/6, Wilanow, 02-991, Warsaw, Poland) as foliar spray at the rate of 2.5 $g.L^{-1}$, on a bi-weekly basis (Table 5). Treatment five (Sulphuric acid) included the use of the Jordan Valley soils as a potting media augmented with the application of 1ml of KSC SulphacideR per pot (Timac Agro, Spain), which was similarly to GreenStim®, applied on a bi-weekly basis (Table 5). The sixth treatment (Kelp) consisted of regular Jordan Valley soil as a potting media, with the soil enriched with the application of 1ml Kelp extract (Vitamoss 50 extract dissolved in 1L per pot; Astra Industrial Complex in Dammam, Saudi Arabia), applied on a bi-weekly basis (Table 5). The last treatment (Compost + Bacteria treatment) consisted of a combination Compost and Bacteria treatment, where Jordan Valley soil was mixed with compost (ratio 1:3) and augmented with the use of 1 g Fulzyme^{TM} bacteria (*Bacillus subtilis and Pseudomonas putida*) per pot, applied at planting.

Support for plants by means of bamboo sticks (25 mm diameter, 1500 mm height) was added to pots between 4 and 6 November 2013. Chemical sprays to control the four major pests and pathogens experienced namely: mites, white fly, *Fusarium* and *Pithium* were applied to pots on 20, 27 and 29 October, with two additional applications on 6 and 8 November 2013 (Table 6).

Data collection. Measurements of plant height (mm) and leaf number were recorded every 15 days. The largest leaf width, as an indication of the leaf area, was also documented. In addition, yield expressed as number of fruit, fruit fresh weight (g), together with fresh root- (g) and shoot weights (g) were determined on the harvest date on 24 January 2014. Thereafter, dry root- (g) and shoot weights (g) were recorded, following a sufficient period of sun-drying, under an average temperature of approximately 30˚C ± 2°C.

Experimental design and statistical analysis. A randomized complete block design was used, with 12 replicates per treatment combination, where treatment and variety were considered the main effects. Growth parameters were analysed by Repeated Measures Analyses of Variance (RANOVA) using Statistica 9.0 (Stasoft, Inc., Tulsa, Oklahoma, USA). A comparison of means was done by means of a one-way ANOVA, and linear models ANOVA, using Bonferroni's LSD posthoc separation test in Enterprise guide, SAS 9.2 (SAS Institute Inc., Cary, USA).

Results

Plant leaf number over time. No interaction between Time, Cultivar and Treatment (p=0.889), or between Cultivar and Treatment (p=0.3387), was obtained (Fig. 1). However, there was a significant interaction between Time and Treatment (p=<0.0001), (Fig. 1A) and also between Time and Cultivar (p=<0.0001) (Fig. 1B). Plant leaf number for plants from all treatments increased significantly over the entire growth period, and also showed significant increases between consecutive dates (Fig. 1A). The highest mean plant leaf number was observed for plants that received the Compost treatment with average of 19.8, which was not significant different from the mean leaf number of 19.2 obtained from plants subjected to the Compost+Bacteria treatment. However, these two treatments differed significantly from the Control treatment with 18.16 leaves, the Sulphuric acid- (17.1), the Kelp- (16.1), the Glycine betaine- (15.8) and lastly, the Bacteria treatment (15.37). The latter three treatments did not differ significantly from each other. When the different cultivars are considered with respect to leaf number, 'Ayah' consistently scored a higher number of leaves throughout the monitoring period compared to 'Bahjah' (Fig. 1B).

Plant leaf number at harvest. No interaction between Treatment and Cultivar was recorded for the final average leaf number at harvest (p=0.6683) (Fig. 2). When considering the impact of the respective treatments on leaf number, the plants from the Compost treatment obtained the highest leaf number at 40.7, which was significantly higher than recorded for the Bacteria treatment, the Glycine betaine-, the Sulphur acid- and the Kelp treatment. However, the number of leaves from the Compost treatment did not differ significantly from either that of plants from the Control treatment or the Compost+Bacteria treatment. The lowest leaf number at harvest for a treatment was 30.7 and was recorded for plants subjected to the Bacteria treatment. However, this low leaf number did not differ significantly from that reported for the Glycine betaine treatment, the Sulphur treatment and the Kelp treatment (Fig. 2A). The number of leaves of 36.0 at harvest for 'Ayah' was significantly higher than that of 30.8 for 'Bahjah' (Fig. 2B).

Plant height over time. For the parameter plant height, no significant interaction between Time, Cultivar and Treatment (*p*=0.3213), or between Cultivar and Treatment (*p*=0.3576), was obtained (Fig. 3). However, a significant interaction between Time and Treatment (*p*=<0.0001), as well as between Time and Cultivar was observed (*p*=<0.0001) (Fig. 3). Plant height for all treatments increased significantly over the entire growth period as expected, and also showed significant increases between consecutive weeks (Fig. 3A). The highest mean plant height at 89.8 cm was achieved in the Compost treatment, however this value did not differ significantly from the Control treatment (80.7 cm) or Compost + Bacteria treatment (81.9cm). The Sulphuric acid treatment produced the shortest plants (71.3 cm), but these did not differ significantly from the Bacteria treatment (76.5 cm), the Glycine betaine (71.6 cm) or the Kelp treatment (75.7 cm). Plant height for the respective cultivars increased significantly between the consecutive weeks. 'Ayah' consistently scored a higher plant height throughout the monitoring period compared to 'Bahjah' (Fig. 3B).

Plant height at harvest. As in the case when plant height was studied over time, no interaction between Treatment and Cultivar for final plant height at harvest was observed (*p*=0.6708) (Fig. 4). The Compost treatment obtained the highest plant height at harvest. This mean plant height was significantly higher than that recorded in plants that received the Sulphur acid treatment, but did not differ significantly from plants representing the remainder of the treatments (Fig. 4A). The plant height for 'Ayah' was significantly higher at 88.1 cm, than that recorded for 'Bahjah' at 70.2 cm (Fig.4B).

Leaf width. No significant interaction (*p* = 0.075) between Treatment and Cultivar emerged with the analysis of the data representing the largest leaf width (Fig. 5). Plant subjected to the Compost treatment scored the highest leaf length, but did not differ significantly from the plant height that was recorded from any of the other treatments. (Fig. 5A). 'Ayah' (20.1 cm) had a significantly broader leaf width compared to that measured for 'Bahjah' (5.6 cm) (Fig. 5B).

Fruit number. No interaction (*p*=0.1417) between Treatment and Cultivar was observed for the parameter fruit number (Fig. 6). The Compost treatment produced the highest number of fruit, which was significantly higher than was harvested from the Control treatment, the

Glycine betaine or the Kelp treatment (Fig. 6A). The yield from the Compost treatment was however not statistically different from that obtained from the Sulphur acid treatment, the Kelp- or Compost+Bacteria treatment. The fruit number obtained for 'Ayah' was significantly higher (6.8) than that recorded for 'Bahjah' (4.6) (Fig. 6B).

Fruit weight. Data analysis for the parameter fruit weight did not produce any interaction between Treatment and Cultivar (*p*=0.3432) (Fig. 7). Considering the results obtained for fruit weight, the Compost treatment obtained the highest fruit weight. This value was significantly higher than that recorded for the Control treatment, the Bacteria-, the Glycine betaine-, the Sulphuric acid treatment or the Kelp treatment (Fig. 7A). However, the fruit weight from the Compost treatment did not differ significantly from the Compost+Bacteria treatment (Fig. 7A). Significant cultivar differences were noted for fruit weight, where the mean fruit weight for 'Ayah' (314.2 g) was significantly higher than that recorded for 'Bahjah' (255.8 g) (Fig. 7B).

Fresh and dry shoot weight. No interaction (*p*=0.8951) between Treatment and Cultivar emerged from the analysis of fresh or dry shoot weight data (Fig. 8; Fig. 9). The Compost treatment obtained the highest fresh shoot weight, with an mean value that was significantly higher than that of the Bacteria treatment, the Glycine betaine-, the Sulphuric acid- or the Kelp treatment. However, the shoot weight of the Compost treatment did not differ significantly from that of the Control treatment or the Compost + Bacteria treatment (Fig. 8A). The fresh shoot weight from plants that received the Glycine betaine treatment was significantly lower than that of plants of the Control treatment, the Compost- or the Compost+Bacteria treatment, but did not differ significantly from the remaining treatments (Fig. 8A). The mean fresh shoot weight for 'Ayah' (273.0 g) was significantly higher than the shoot weight recorded for 'Bahjah' (185.5 g) (Fig. 8B).

Considering results from the dry shoot weight analysis, the Compost treatment scored the highest dry shoot weight (Fig. 9A), which was significantly higher than all the other treatments except for the dry shoot weight obtained from plants that received the Compost+Bacteria treatment. The latter treatment however did not differ significantly from the remaining treatments (Fig. 9A). Dry shoot weight obtained for 'Ayah' (35.7 g) was significantly higher than that recorded for 'Bahjah' (22.6 g) (Fig. 9B).

Fresh and dry root weight. Similar to that reported for fresh and dry shoot weight, no interaction emerged between Treatment and Cultivar from the analysis of fresh or dry root weight data (*p*= 0.1711 and 0.4584 respectively) (Fig. 10; Fig. 11). However, fresh root weights for the respective treatments (Figs. 10A; 10B) did not differ significantly from each other, even though the Kelp treatment obtained the highest mean fresh root weight (Fig. 10A). The fresh root weights obtained for 'Ayah' (10.1 g) and 'Bahjah' (7.6 g) did not differ significantly from each other (Fig. 10B).

A similar trend in dry root weight accumulation were observed for the fresh root weight, where the treatments did not differ significantly from each other, although the Bacteria treatment had the highest mean dry root weight (Fig.11A). The mean dry root weight between 'Ayah' (2.2 g) and 'Bahjah' (0.8 g) did not differ significantly from each other (Fig. 11B).

Plant dry shoot: root ratio. No interaction (p=0.7257) between Treatment and Cultivar emerged for the ratio of dry shoot weight:dry root weight (Fig. 12). In addition, no significant difference was obtained for this ratio between treatments (Fig. 12A) or between the respective cultivars 'Ayah' (28.3) and 'Bahjah' (32.6) (Fig.12B).

Discussion

Increased salinity of irrigation water and agricultural soils will undoubtedly have considerable impacts on plant health and commercial crop production potential, as excess salinity impacts on the available water to plants and thereby inducing plant stress (Warrence et al., 2003). Physiological and biochemical effects of salinity on crop plants include reduced cell- and leaf expansion, lower levels of cellular and metabolic activities, stomatal closure, photosynthetic inhibition, cavitation, membrane and protein destabilization, reactive oxygen species (ROS) production and finally cell death (Taiz et al., 2015). These effects alone, or in combination with each other, lead to a decrease in plant height, a reduction in leaf number, slower root development and lower fresh and dry shoot weight - all resulting in a decrease in yield and produce quality Hussain et al., (2009)

Biostimulants have shown to be beneficial by providing an amelioration mechanism to assist the plant to combat salinity and all its side effects (Van Oosten et al., 2017). In our study, the Compost treatment produced the best plant performance for both vegetative and reproductive structures. In general, the compost-containing treatments (Compost and Compost + Bacteria) resulted in the highest leaf number (Figs. 1A; 2A), plant height (Fig 3A), largest leaf width and length (Figs. 5A; 6A), highest fresh and dry shoot weight (Figs. 8A; 9A) and the top fruit number and weight (Figs. 6A, 7A). These compost-related treatments can therefore be considered to be the most effective biostimulants under our simulated salinity conditions for both 'Ayah' and 'Bayah', thereby also confirming various reports (Lakhdar et al., 2009; Wang et al., 2014). It furthermore concured with Badar et al. (2015) that the effect of both composted and non-composted organic waste on chickpea production. Badar et al.

(2015) reported plants treated with composted sawdust to achieve the highest dry weight, fresh weight and root length, while plants exposed to composted peanut shells obtained the longest shoot length. Similar results were also reported in a study conducted in Nigeria on okra (*Abelmoschus esculentus*), where vegetative and reproductive responses were recorded with the use of compost (Adebayo et al., 2013). In this study a significantly increase in stem growth, number of leaves, number of fruits and fruits weight were reported on using compost amended with mineral fertilisers.

The positive results obtained in our study from the compost-containing treatments could possibly be ascribed to various factors known to be associated with composting. These factor include: additional nutrient mineral supplementation; increased mineral uptake through micro-organism facilitation; stimulating of root growth via phyto-hormones resulting from the micro-organism activity, together with improved water management of the pot medium and buffering of the planting media pH (Crouch et al., 1992, Durand et al., 2003; Stirk et al., 2003). However, these factors were not quantified in this study.

Results from the Kelp treatment (Vitamoss 50), which is extracted from *Ascophyllum nodosum,* showed a trend for higher root weight which is well aligned with its known mode of action via phyto-hormones, yet the trend observed was not significantly different from the other treatments (Fig. 10A and 11A). In a study on okra, Papenfus et al. (2013) reported that a treatment with kelp, extracted from *Ecklonia maxima,* had no effect on the fresh and dry root weight under condition of adequate nutrition. Thus, the different sources of sea weed extracts could partly explain the different response observed in our study. However, when nutrient deficiencies of N, P and K occurred, the kelp treatment achieved the highest mean fresh and dry root weight in the okra study. The highest shoot length in the okra study was also associated with the kelp treatment, whereas our results on tomato reported the Kelp treatment to produce high fresh and dry shoot weight and leaf number, but not shoot length. When the effect of kelp on the roots of mung beans under various pH and water hardness conditions was studied by Arthur et al. (2013), the kelp product (Kelpak) was found to be most effective at neutral pH, This pH dependant mode of action of kelp-based products that could be one of the reasons why in our research that was conducted on alkaline soils, no significant differences between the Kelp treatment versus other biostimulant treatments were found.

Results from our study showed a trend for the highest mean dry weight production with the Bacteria treatment (Fig.11A), although it was not statistically different from the other treatments. Mohammed and Gomaa (2012) inoculated radish seeds cultivated under saline conditions with *Bacillus subtilis*. A significant increase in both the fresh and dry root weight was recorded. Similarly Abeer et al. (2015) reported the improvement of shoot and root growth of basil grown under saline conditions in the presence of *Bacillus* bacteria, when compared to a control. There is thus extensive evidence for the positive role of *B. subtilis* on vegetative growth of crops under saline conditions. By contrast, our results could not provide sufficient evidence for the efficacy of the Bacteria treatment to improve productivity of tomatoes under our particular saline conditions. The method of application of treatment – a seed treatment vs soil applied treatment could partly explain the lack efficacy of the Bacteria treatment reported in our research. In addition, crops or even cultivars within a particular crop are known to react differently on treatments. Finally, our Bacteria treatment comprised of both *B. subtilis* and *P. putida,* thus a known interaction between the two organisms that was not quantified in our study may have reduced the benefit that was expected to be extended to enhance the tomato production (Powers, 2015). Furthermore, these bacteria are often associated with biocontrol. A possible explanation of the reduced growth above ground that was observed compared to the other treatments may be related to the initiation of a defence response of the plant following the application of the Bacteria treatment, with the associated energy cost of this process and greater emphasis on increasing root dry weight in this case. Our results thus suggest that this treatment may not be ideally suitable to provide enhance production under saline conditions, as the mode of action of this treatment favours pathogenic challenges.

The GreenStim^{TM} (Glycine Betaine) treatment did not result in significant response Rezaei et al. (2012) reported an increase in yield and other positive vegetative traits for soybean grown under saline conditions when exposed to exogenous glycine betaine. An increase in glycine betaine concentration increased the efficacy, with the high concentration treatment of 7.5 g.ha^{-1} producing the best results, while in our study we only used a much lower dosage of 2.5 kg.ha^{-1}. The positive results reported by Rezaei et al. (2012) on using a higher concentration were also confirmed by Kausar et al. (2014) and Chaum and Kirdmanee (2009). Thus, results may be improved if the dosage is increased. In addition, Aldesukuy et al. (2012) introduce the synergistic effect of salicylic acid and glycine betaine for enhanced alleviation of drought stress in wheat when compared to when either product was used separately. This approach was not followed in this study, and could be explored in future.

KSC Sulphacide as a treatment did not emerge as a possible amelioration alternative in our study on tomatoes. In fact, it was evident that, for some parameters such as leaf number, plant height, leaf width and fruit weight (Figs. 2A, 4A, 5A, 7A), the effect was either similar to that of the control or even revealed a negative impact, despite many reports on other crops and elsewhere that documented a positive effect on soil amelioration (Abdelhamid et al. 2013; Niazi et al., 2001; Ramzan et al., 1989). However, a study by Zia et al. (2007) indicated sulphuric acid as a soil ameliorant to be effective in increasing wheat yield, but to have a detrimental effect on kallar grass yield, similar to our findings with tomato.

A study by Kahlaouil et al. (2011) reported that the three tomato cultivars ‘Rio Tinto’, ‘Rio Grande’ and ‘Nemador’ were negatively affected by saline water as noted by reductions in leaf area, petiole size, and stem and root weight, although the fruits were apparently less affected. ‘Rio Tinto’ and ‘Nemador’ were more affected than ‘Rio Grande’ that was considered to be a better adapted cultivar to saline conditions. No previous reports to date on plant performance of ‘Ayah’ of ‘Bahjah’ under saline conditions could be source. In our study, ‘Ayah’ out performed ‘Bahjah’ significantly in almost all criteria recorded (Figs 1-9B; 11B), except for the parameter of fresh root weight and dry shoot:root where difference were found to be non-significant. ‘Ayah’ should be favoured over ‘Bahjah’ for production under moderate to severe saline conditions.

Conclusion

Based on results presented we can conclude that the Compost treatment treatment showed efficacy to ameliorate the impact of salinity on tomatoes as could be observed by enhanced vegetative growth, including leaf number, plant height, leaf area, fruit number, fresh shoot weight and dry shoot weight. Thus, it is of importance that the mode of action of the compost under saline conditions should be investigated in order to further to explore the use of compost under such conditions. Despite the apparently direct impact of the Kelp treatment on the fresh root weight along with the ability of the Bacteria treatment to promote dry root weight, these treatments did not promote tomato production effective under saline conditions compared to the Control treatment. It may be possible that an elevated kelp concentration could have provided improve results. Furthermore, as the mode of action of the bacteria used in the Bacteria treatment appeared to be counterproductive under saline conditions, it is suggested that alternative species should be investigated in a next study.

It is further recommended that this research is extended over two or more seasons, in addition to exploring a wider concentration range and more combinations of the various ameliorants in order to confirm results and/or allow for the adjustment of protocols. Mineral analyses of both leaf material, as well as the potting soil before and after treatment should be included in future research. This information, in addition to the inclusion of physiological measurements like photosynthesis and stomatal conduction, will assist in quantifying the relief provided by the amelioration and may assist in elucidating the mode of action the different ameliorants may provide under commercial conditions.

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Tables

Table 1. The physical and chemical properties of native Jordan Valley soil as was used as a planting medium when the response of two tomato varieties, ‘Ayah’ and ‘Bahjah’, to a range of soil ameliorants within a saline soil environment was evaluated.

Soil Characteristics	pH[w]	EC[x]	%N	P (mg.L^{-1})	K (mg.L^{-1})	% $CaCO_3$	Exch. Ca[y]	Na %[z]	Cl (mg.L^{-1})
	7.9	2.3	0.3	17.7	219.5	30.0	0.04	6.1	110.0

[w]Paste extract; [x]electrical conductivity as dS.L^{-1}, paste extract; [y]exchangeable Ca as meq.100g^{-1}; [z] % exchangeable sodium percentage

Table 2. The fertigation solution nutrient composition per 1000 L as was used in a study which assessed the effect of a range of soil ameliorants by means of the response two tomato varieties, ‘Ayah’ and ‘Bahjah’, to soil salinity.

Concentration	MAP	$CaNO_3$	KNO_3	$(NH_4)NO_3$	$MgSO_4$	Cu EDTA	Fe EDDHA	Zn EDTA	Mn EDTA	B_2O_3	Na_2MoO_4
g.1000L^{-1}	137.0	437.5	560.0	44.5	461.5	0.5	8.5	1.2	1.2	1.0	0.05

MAP: Mono-ammonium Phosphate; KNO_3: Potassium Nitrate; $(NH_4)NO_3$: Ammonium Nitrate; $MgSO_4$: Magnesium Sulphate; B_2O_3: Boric acid; Na_2MoO_4: Sodium Molybdate; $CaNO_3$: Calcium Nitrate

Table 3. Readings of pH, electrical conductivity (EC measured as mS.L^{-1}) and solution temperature (˚C) of the fertigation mixture in nine individual 1000L tanks, following 1 hour of mixing.

Solution Readings	Tank 1	Tank 2	Tank 3	Tank 4 A[z]	Tank 4 B[z]
pH	6.52	6.58	6.44	6.34	6.24
EC (dS.L^{-1})	6.45	6.62	6.49	6.53	4.37
Temperature (˚C)	24.2	23.8	23.2	22.3	22.4

Solution Readings	Tank 5	Tank 6	Tank 7	Tank 8	Tank 9
pH	6.3	6.27	6.33	6.37	6.29
EC (mS.L^{-1})	3.13	4.33	4.54	4.16	4.13
Temperature (˚C)	23.2	22.7	22.1	21.5	22

[z]Tank 4 required a downward EC adjustment at the phenological stage of flowering to ensure the continuation of fruit development until production.

Table 4. The treatment description with the application timing and rates of various soil ameliorants as used in a study which evaluated the response of two tomato varieties, 'Ayah' and 'Bahjah', to these soil ameliorants, within a saline environment.

Treatment	Description	Application rate	Timing
Control	Control (Regular Jordan Valley soil)	-	-
Compost	Regular Jordan Valley soil + Compost	Soil mixture ratio of 1:3	at planting
Bacteria	Regular Jordan Valley soil + Fulzyme Bacteria	Soil mixture with the addition of 1g bacteria formulation.pot^{-1}	at planting
Glycine	Regular Jordan Valley soil + GreenStim^{TM}	Foliar application at 2.5 g.L^{-1}	every 14 days
Sulphur	Regular Jordan Valley soil + KSC Sulphacide soil	Soil application of 1 ml.L^{-1} KSC.pot^{-1}	every 14 days
Kelp	Regular Jordan Valley soil + Kelp extract (Vita moss)	Soil application of 1 ml.L^{-1} Kelp.pot^{-1}	every 14 days
Compost + Bacteria	Regular Jordan Valley soil + Compost 1:3 + Fulzyme Bacteria	Soil & compost with 1g bacteria formulation.pot^{-1}	at planting

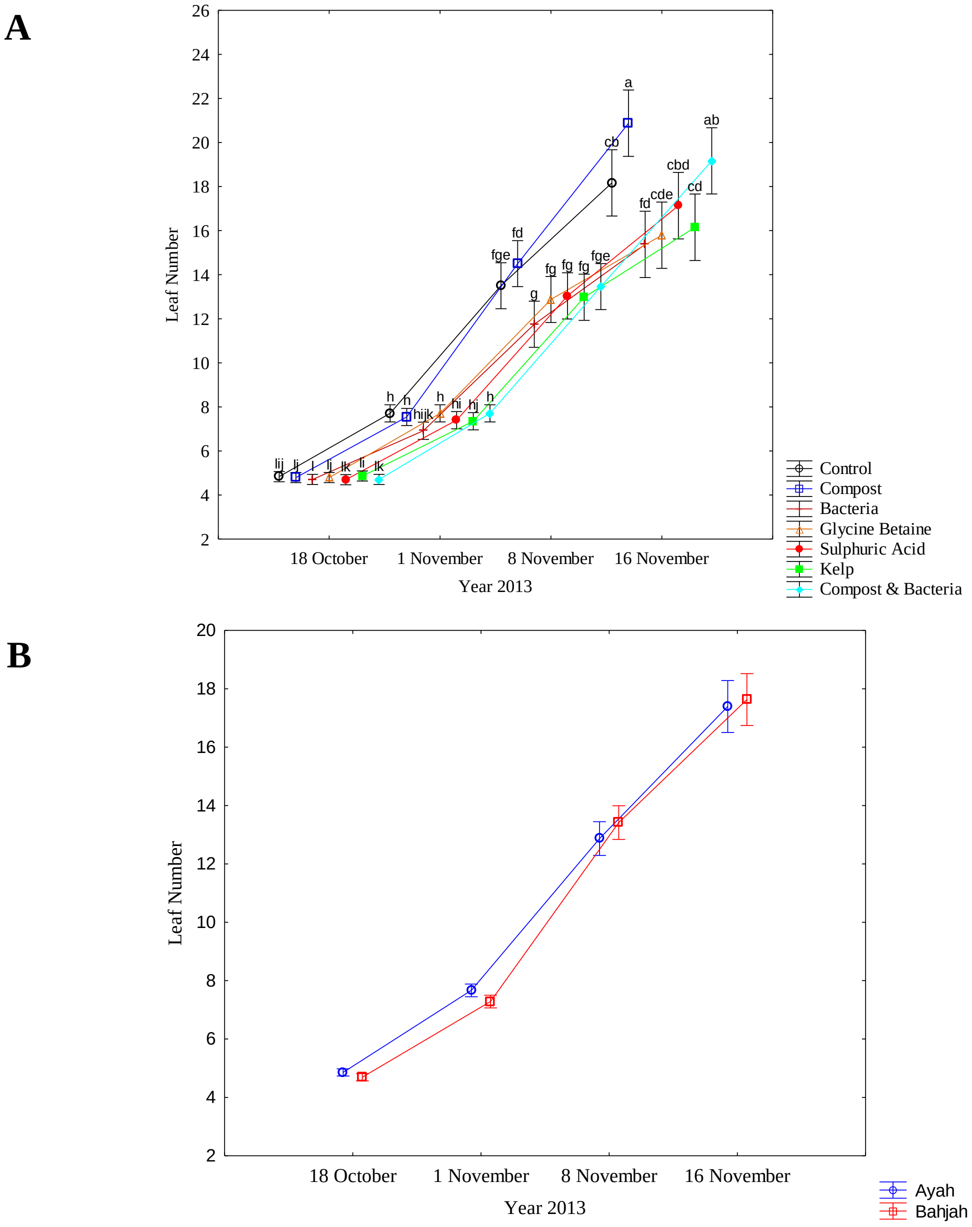
Table 5. Chemical sprays as were applied to control the relevant pests and pathogens in a study which evaluated the response of two tomato varieties, 'Ayah' and 'Bahjah', to a range to soil ameliorants within a saline soil environment.

	Date (2013)	Common Name	Active Ingredient
1	20 Oct	Super pectin 5% & Dislaz 25EC	Ibamectin benzoate & Deltamethrin
2	27 Oct	Attack Super 18EC	Abamectin 1.8
3	27 Oct	Adozim 50% EC & Proplant 72.2 SL	Carbendazim + Propamocarb Hydrochloride
4	06 Nov	Atack Super 18EC	Abamectin 1.8
5	08 Nov	Hymexate	Hymexazol

	Rate of Application	Method of Application	Application target pest/pathogen
1	5g + 25 ml.20 L^{-1}	Foliar Spray	Mites & white flies
2	10 g.20L^{-1}	Foliar Spray	Mites
3	200 ml + 200 ml.200 L^{-1}	Soil application	*Fusarium*
4	150 ml.200 L^{-1}	Foliar Spray	Mites
5	3 ml.L^{-1}	Soil application	*Pithium*

Table 6. The composition of a range of biostimulants used as ameliorants in a study which evaluated their efficacy to improve production in two tomato varieties, 'Ayah' and 'Bahjah', grown within a saline soil environment.

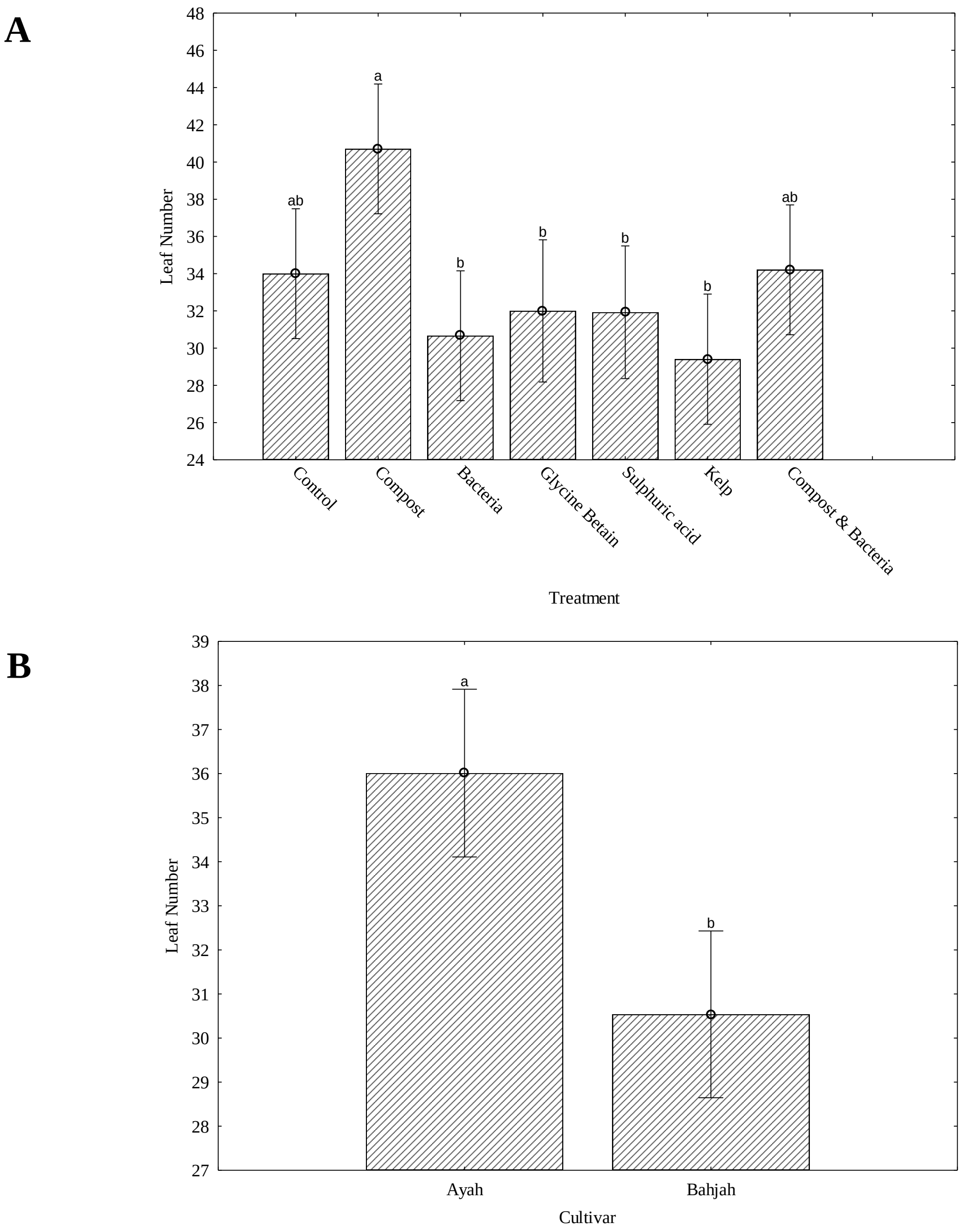
Common Name	Active Ingredients
Compost	50 % Coco peat + 50 % Blumenerde Cocco Peat: 100 % Cocconut Peat as sourced from Pakistan Blumenerde: A mixture of fully decomposed, raised bog-peat and clay
Fulzyme^{TM}	*Bacillus subtilis* + *Pseudomonas putida* 2x0^{10}.gm^{-1}
GreenStim®	30 % of 97% Glycine betaine (GreenStim^{R}) & 12.5 % CaO
KSC Sulphacide^{R}	15 % Total N (1 % Organic + 14 % Urea) + 41 % SO_3,
Vita Moss 50	Kelp, Seaweed extract 50 % ($^{w}/_{v}$)



Leaf number	F- value	Pr>F
Treatment	6.653	<.0001
Cultivar	7.487	0.0070
Time	1231.483	<.0001
Treatment*Cultivar	1.146	0.3387
Time*Treatment	**3.529**	**<.0001**^{z}
Time*Cultivar	**15.32**	**<.0001**
Time*Treatment*Cultivar	0.661	0.8897

^{z}p-values in printed in bold is significant at the 5% confidence level

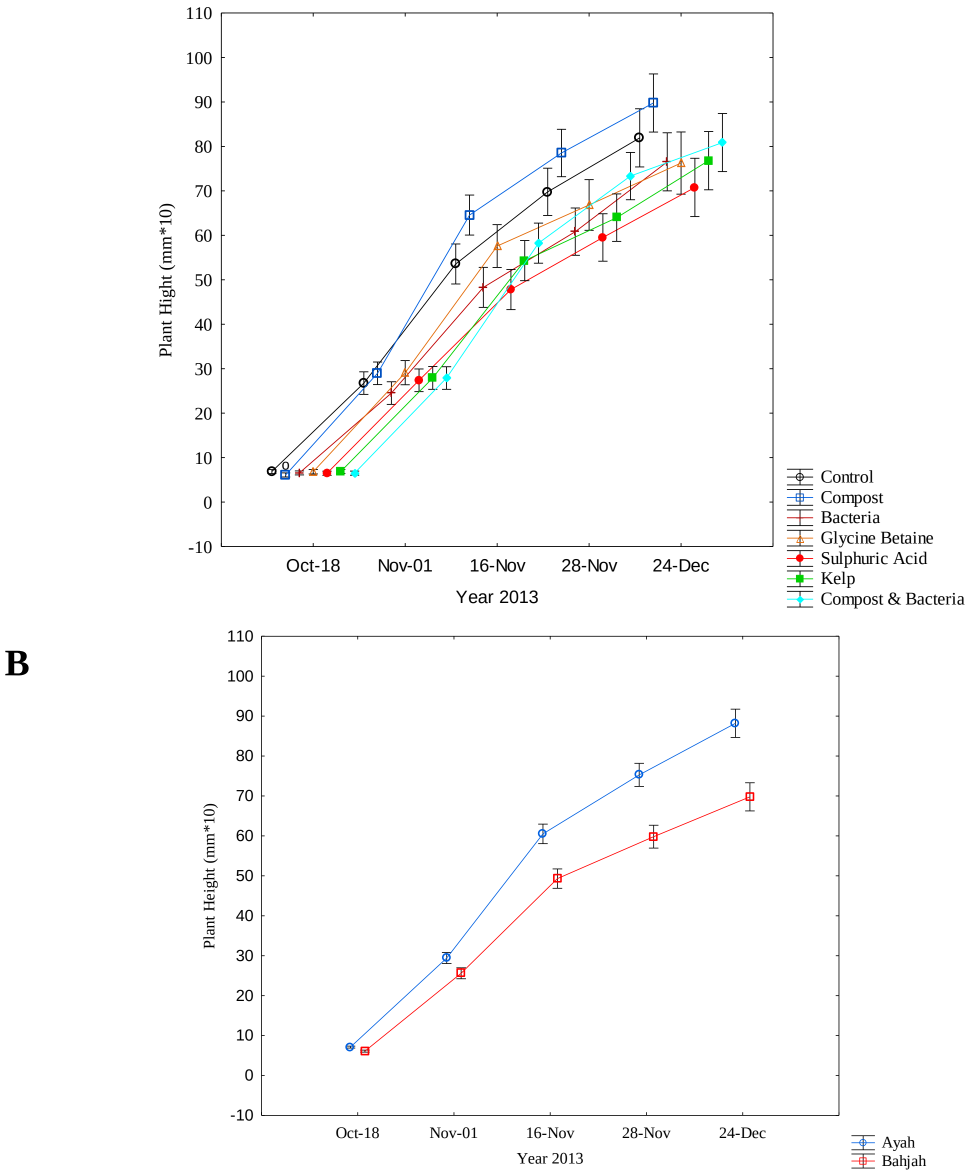
Fig. 1. Plant leaf number of two determinate tomato varieties ‘Ayah’ and ‘Bahjah’ grown with standard fertigation and 3g.L^{-1} NaCl from transplanting to harvest, whilst subjected to six biostimulant treatments to alleviate salinity stress as measured over 90 days from 18 Oct 2013 to 25 Jan 2014 with A as treatment over time, and B as variety over time.



Leaf number at harvest	F-value	Pr>F
Treatment	**6.899**	**0.0008**
Cultivar	**0.206**	**0.0004**^{z}
Treatment*Cultivar	1.257	0.6682

^{z}p-values in printed in bold is significant at the 5% confidence level

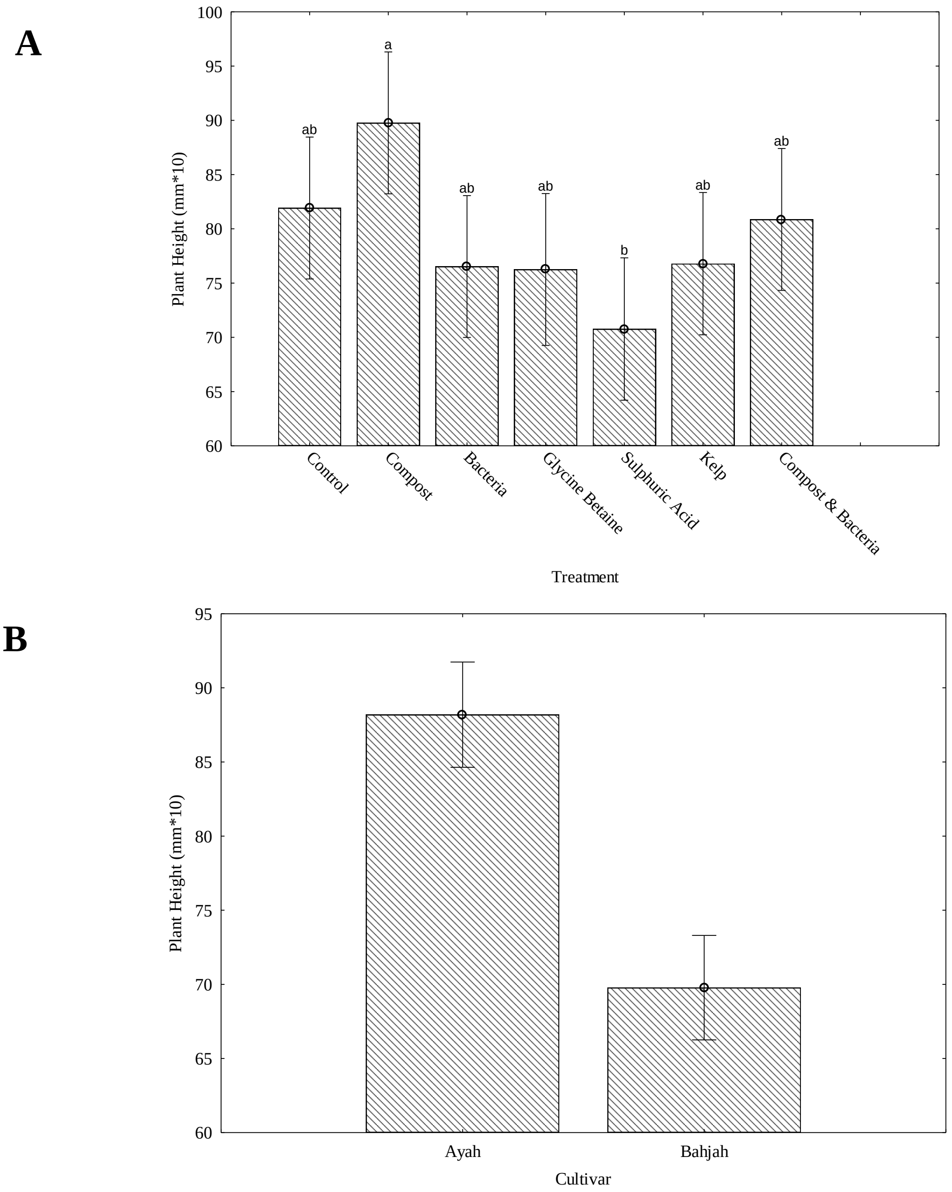
Fig. 2. Plant leaf number as measured at harvest on 25 January 2014 of two determinate tomato cultivars 'Ayah' and 'Bahjah' (B) grown with standard fertigation and 3 g.L^{-1} NaCl from transplanting to harvest, whilst subjected to six biostimulant treatments (A) to alleviate salinity stress.



Plant height	F-value	Pr>F
Intercept	5336.007	<.0001
Treatment	4.977	0.0001
Time	2214.529	<.0001
Treatment*Cultivar	1.113	0.3576
Time*treatment	**4.444**	**<.0001**^{z}
Time*Cultivar	**34.806**	**<.0001**
Time*Treatment*Cultivar	1.1114	0.3213

^{z}p-values in printed in bold is significant at the 5% confidence level

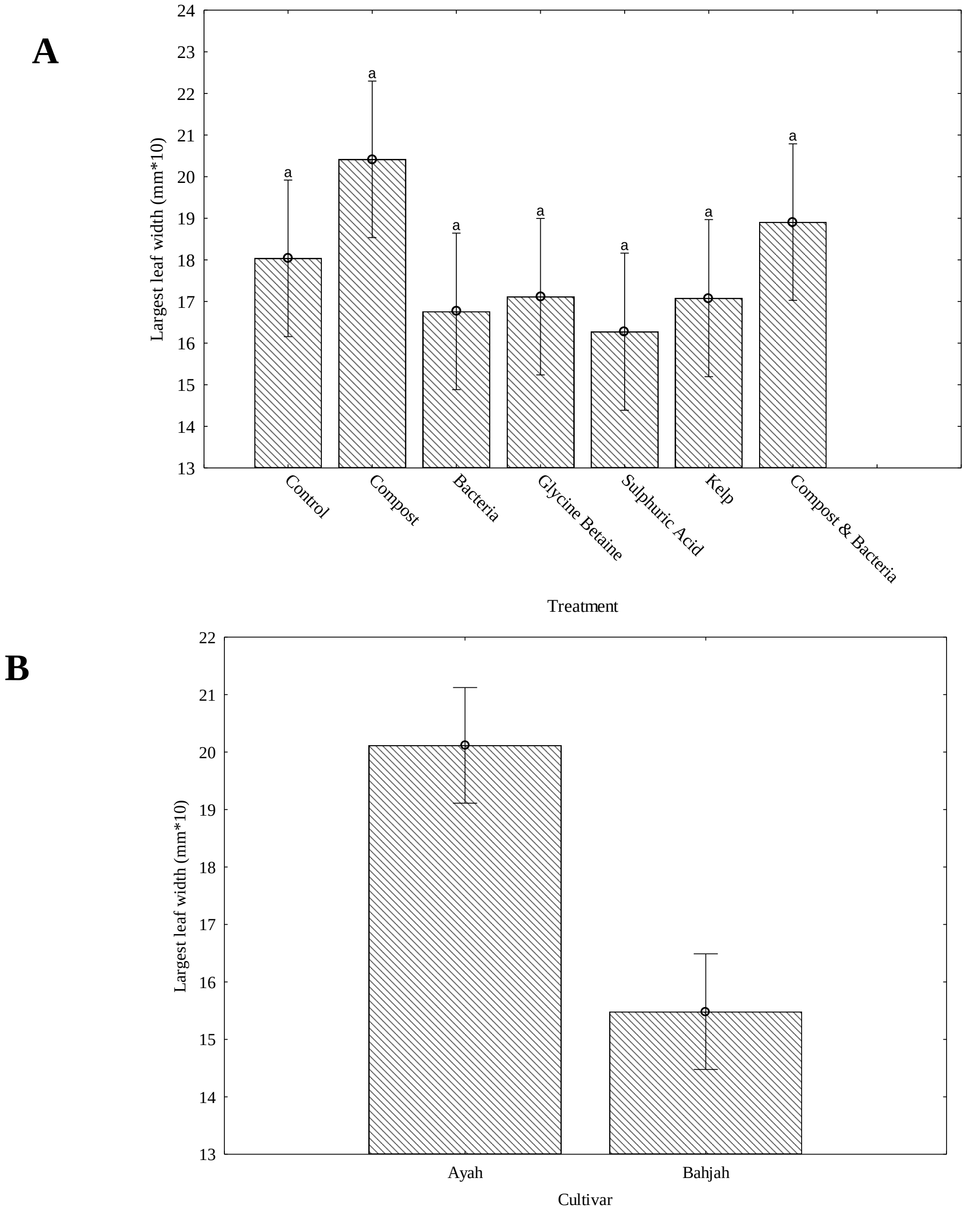
Fig. 3. Plant height (mm*10) of two determinate tomato varieties ‘Ayah’ and ‘Bahjah’ (B) grown with standard fertigation and 3 g.L^{-1} NaCl from transplanting to harvest, whilst subjected to six biostimulant treatments (A) to alleviate salinity stress as measured over 90 days from 18 Oct 2013 to 25 Jan 2014.



Plant height (mm*10) at harvest	F-value	Pr>F
Treatment	**3.237**	**0.0051**
Cultivar	**52.965**	**<.0001**^{z}
Treatment*Cultivar	0.674	0.6709

^{z}p-values in printed in bold is significant at the 5% confidence level

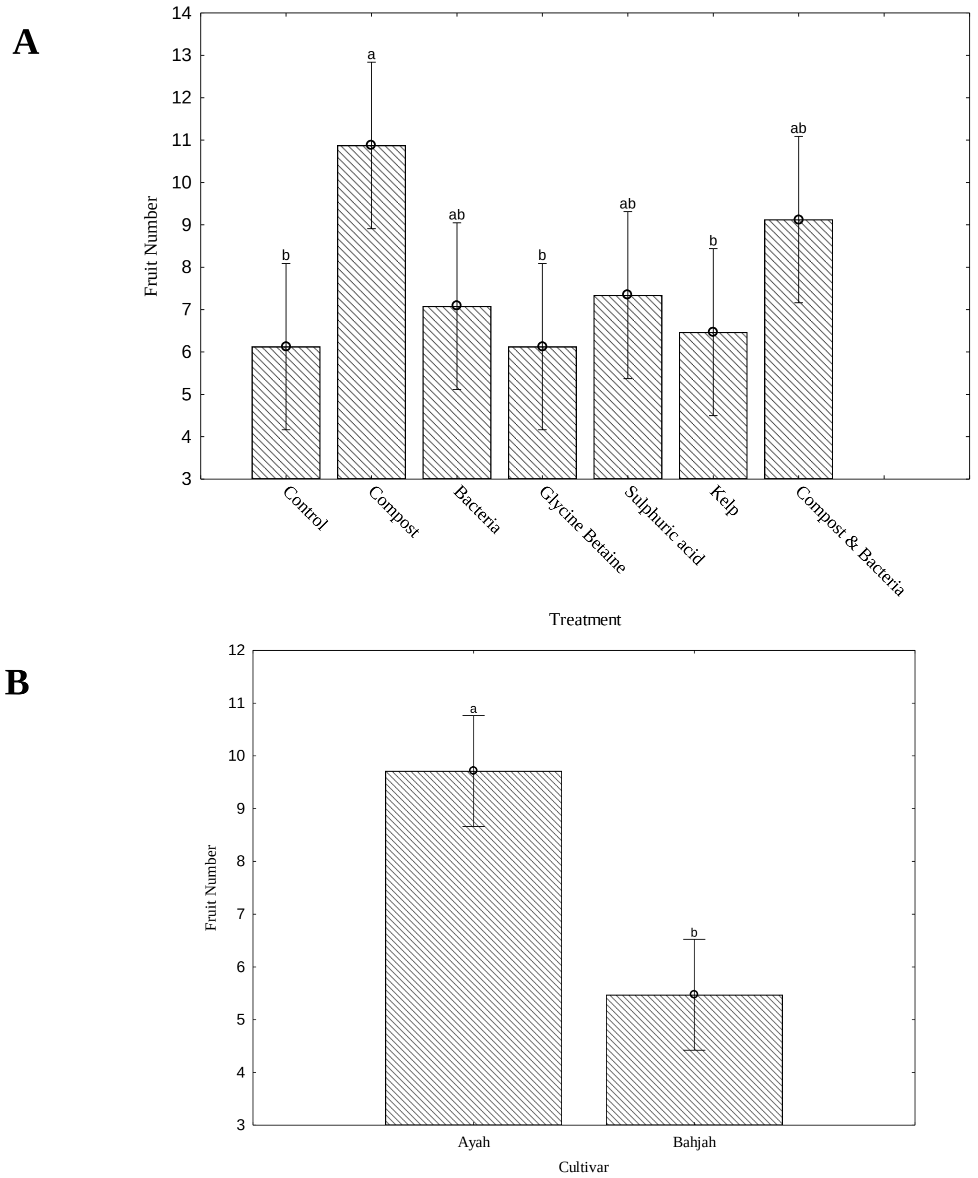
Fig. 4. Plant height at harvest (mm*10) of two determinate tomato cultivars ‘Ayah’ and ‘Bahjah’ (A) grown with standard fertigation and 3 g.L^{-1} NaCl from transplanting to harvest, whilst subjected to six biostimulant treatments (B) to alleviate salinity stress as measured at harvest on 25 January 2014.



Largest leaf width	F-value	Pr>F
Block	6.29	<.0001
Treatment	**3.29**	**0.0046**
Cultivar	**57.19**	**<.0001**[z]
Treatment*Cultivar	1.96	0.0750

[z] p-values in printed in bold is significant at the 5% confidence level

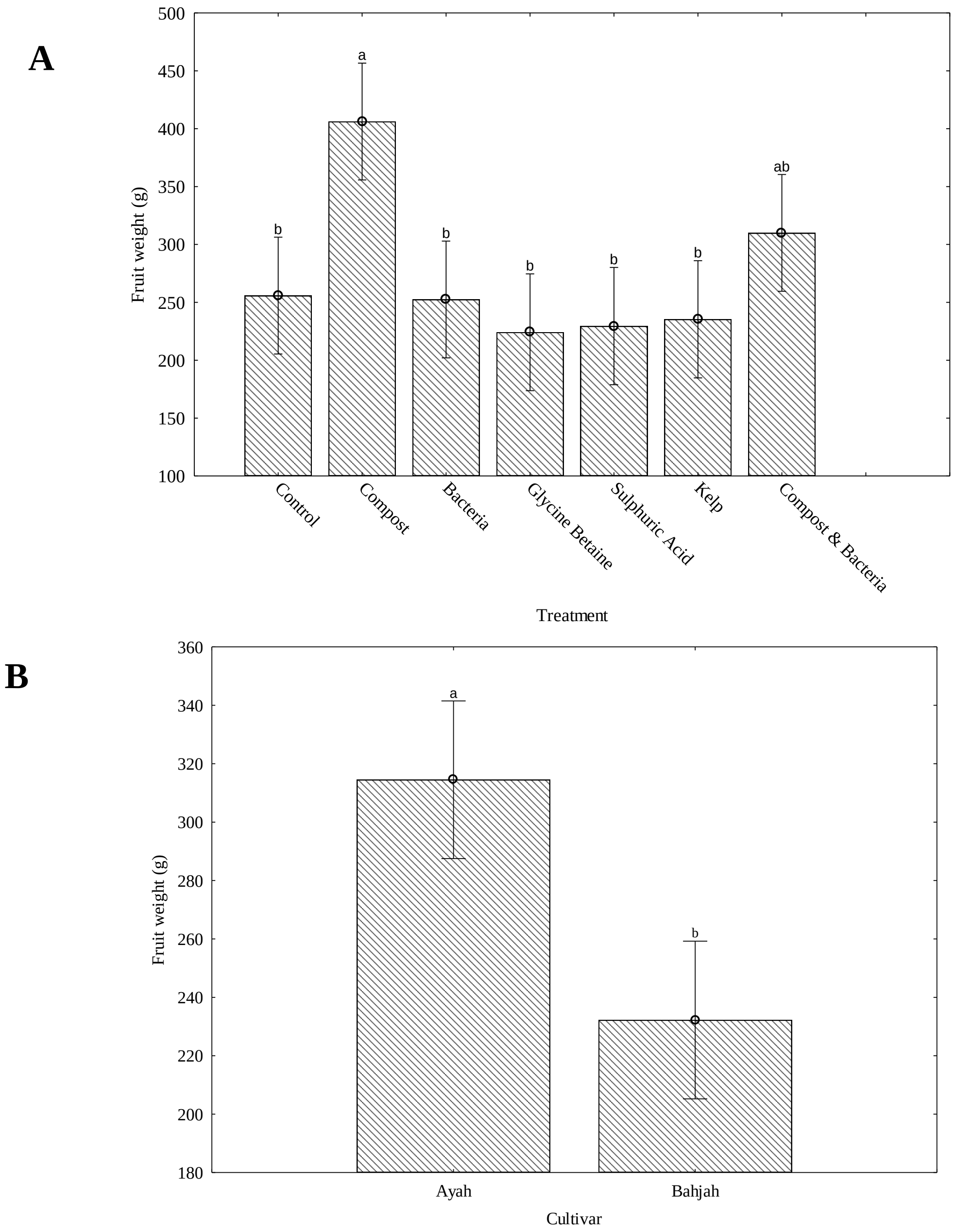
Fig. 5. Largest leaf width (mm*10) of two determinate tomato varieties ‘Ayah’ and ‘Bahjah’ (B) as measured on 8 November 2013. Plants were grown with standard fertigation and 3 g.L^{-1} NaCl from transplanting to harvest, whilst subjected to six biostimulant treatments (A) to alleviate salinity stress.



Fruit Number	F-Value	Pr>F
Block	19.48	0.0480
Treatment	**41.55**	**0.0237**
Cultivar	**31.77**	**<.0001**^{z}
Treatment*Cultivar	6.29	0.1418

^{z}p-values in printed in bold is significant at the 5% confidence level

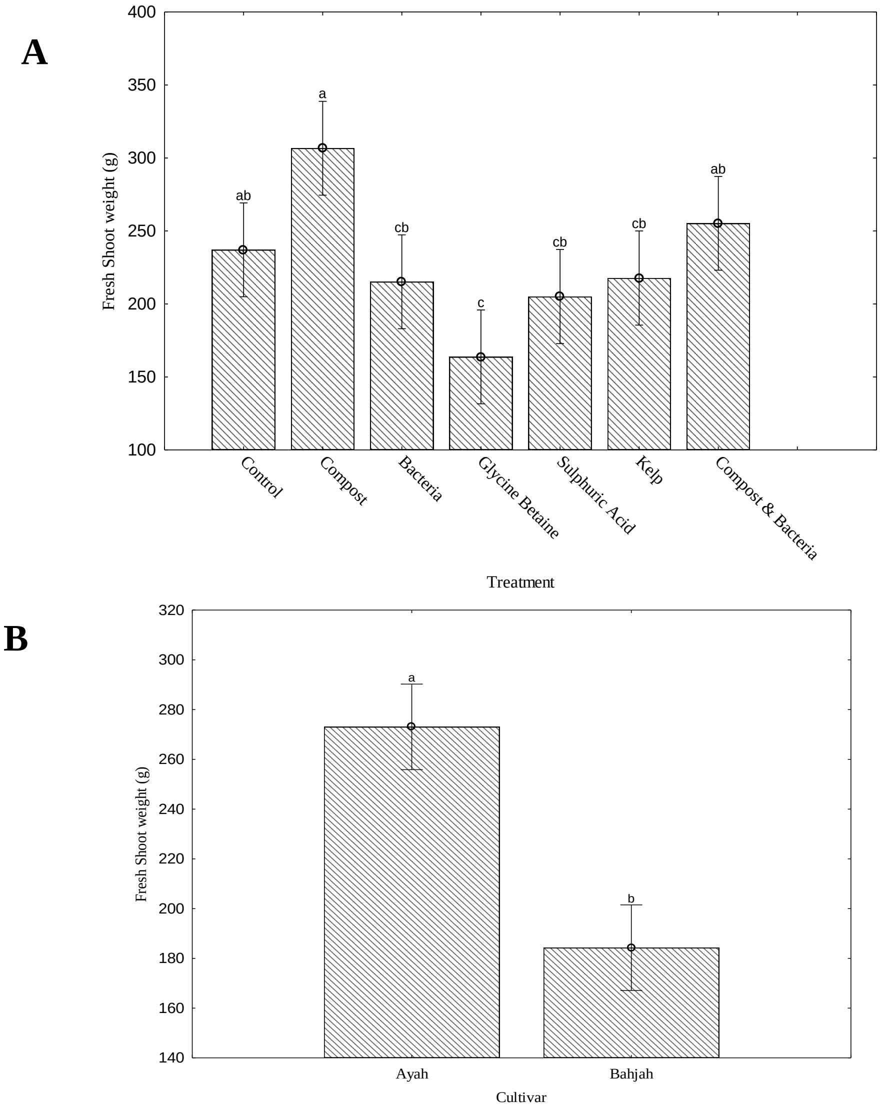
Fig. 6. Total average fruit number delivered by two determinate tomato cultivars ‘Ayah’ and ‘Bahjah’ (B) before or at harvest on 25 January 2014. Plants were grown with standard fertigation and 3 g.L^{-1} NaCl from transplanting to harvest, whilst subjected to six biostimulant treatments (A) to alleviate salinity stress.



Fruit weight	F-value	Pr>F
Block	5.77	<.0001
Treatment	**8.79**	**<.0001**
Cultivar	**24.1**	**<.0001**^{z}
Treatment*Cultivar	1.14	0.3432

^{z}p-values in printed in bold is significant at the 5% confidence level

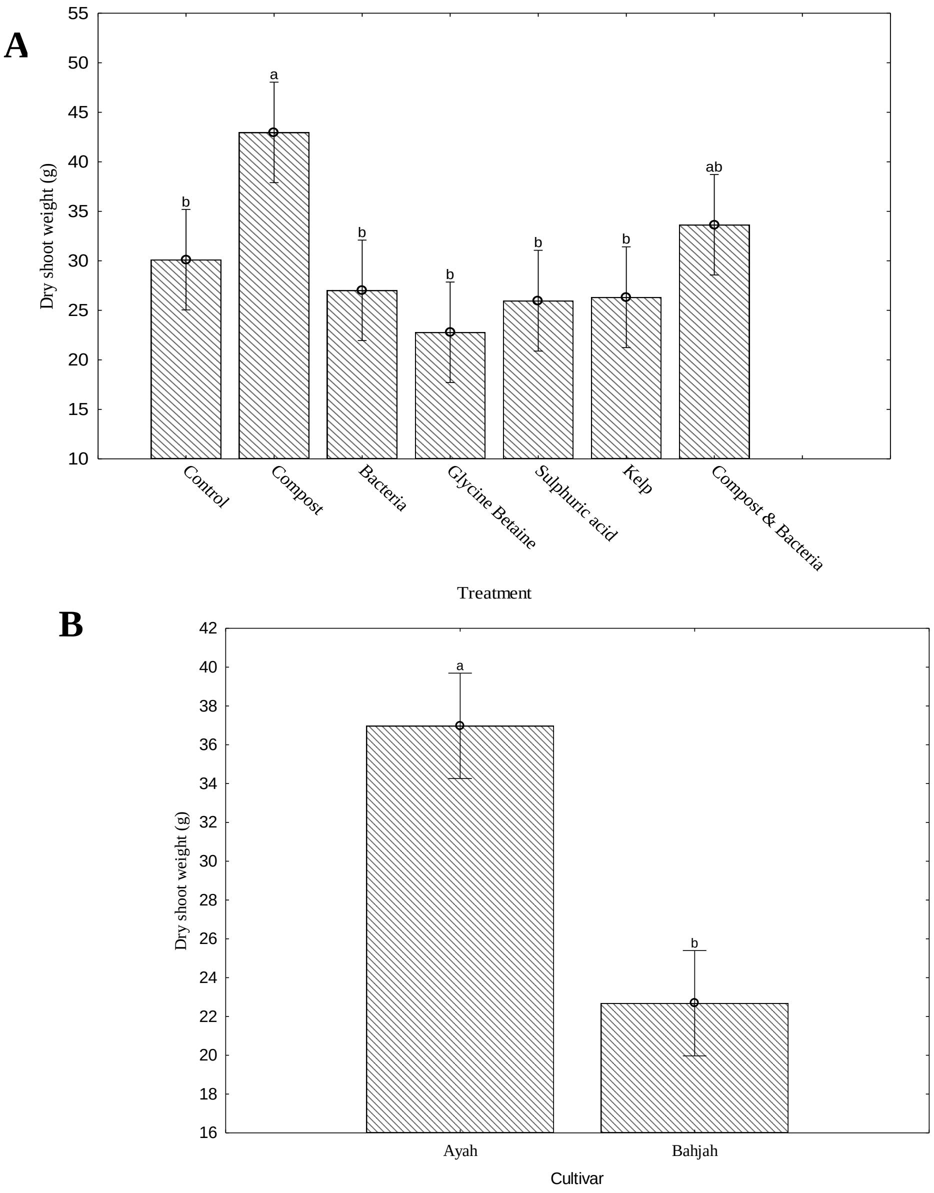
Fig. 7. Plant fruit weight (g) as measured at harvest on 25 January 2014 of two determinate tomato cultivars ‘Ayah’ and ‘Bahjah’ (B) grown with standard fertigation and 3 g.L^{-1} NaCl from transplanting to harvest, whilst subjected to six biostimulant treatments (B) to alleviate salinity stress.



Fresh shoot weight	F-value	Pr>F
Block	3.03	0.0011
Treatment	**8.19**	**<.0001**
Cultivar	**58.17**	**<.0001**[z]
Treatment*Cultivar	0.37	0.8951

[z] p-values in printed in bold is significant at the 5% confidence level

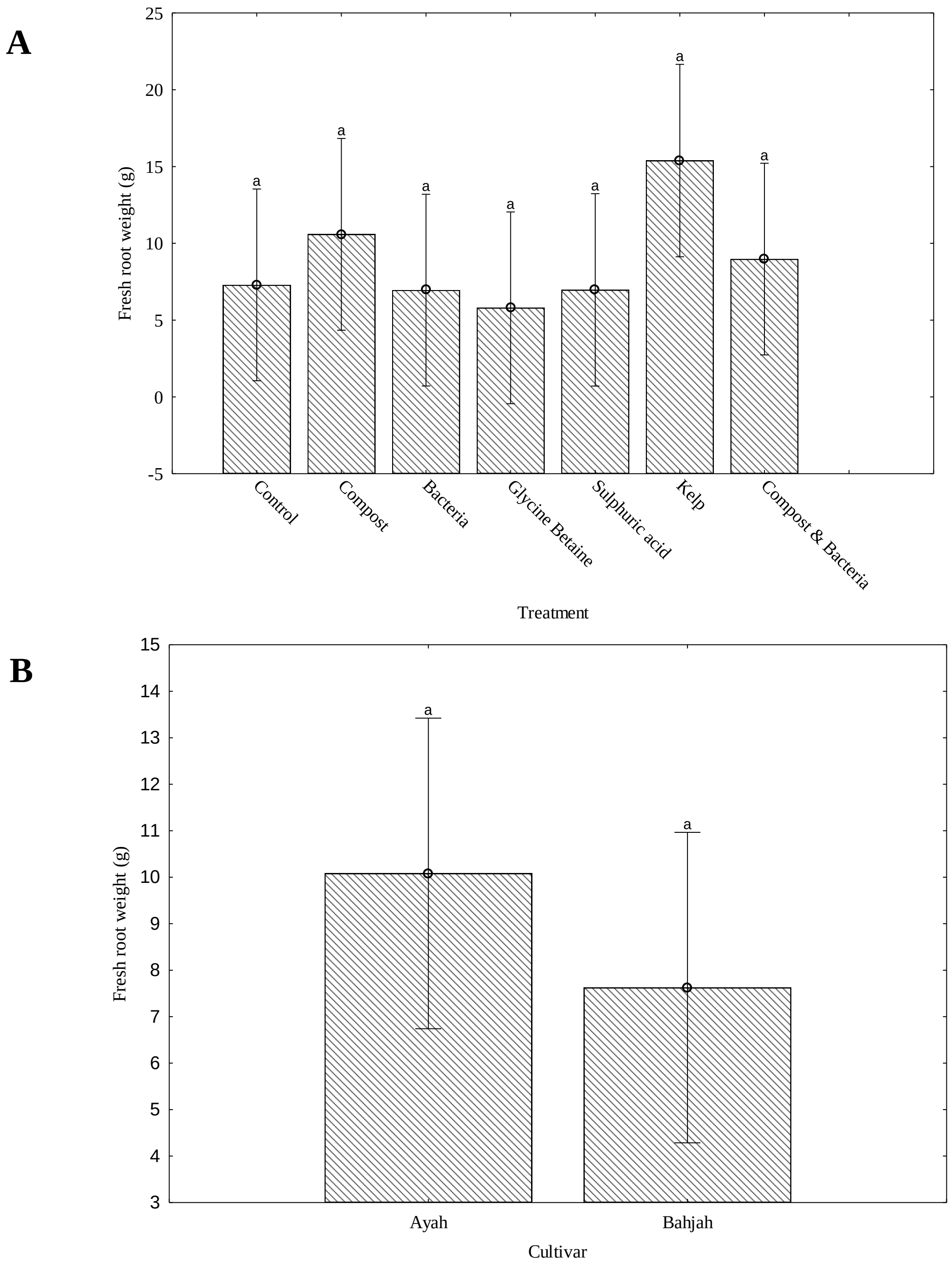
Fig. 8. Plant fresh shoot weight (g) of two determinate tomato cultivars ‘Ayah’ and ‘Bahjah’ as measured at harvest on 25 January 2014 after being cultivated with standard fertigation and 3 g.L^{-1} NaCl from transplanting, whilst being subjected to six biostimulant treatments to alleviate salinity stress.



Dry shoot weight	F Value	Pr>F
Block	4.72	<0.0001
Treatment	**6.63**	**<0.0001**
Cultivar	**65.14**	**<0.0001**[z]
Treatment*Cultivar	1.53	0.1711

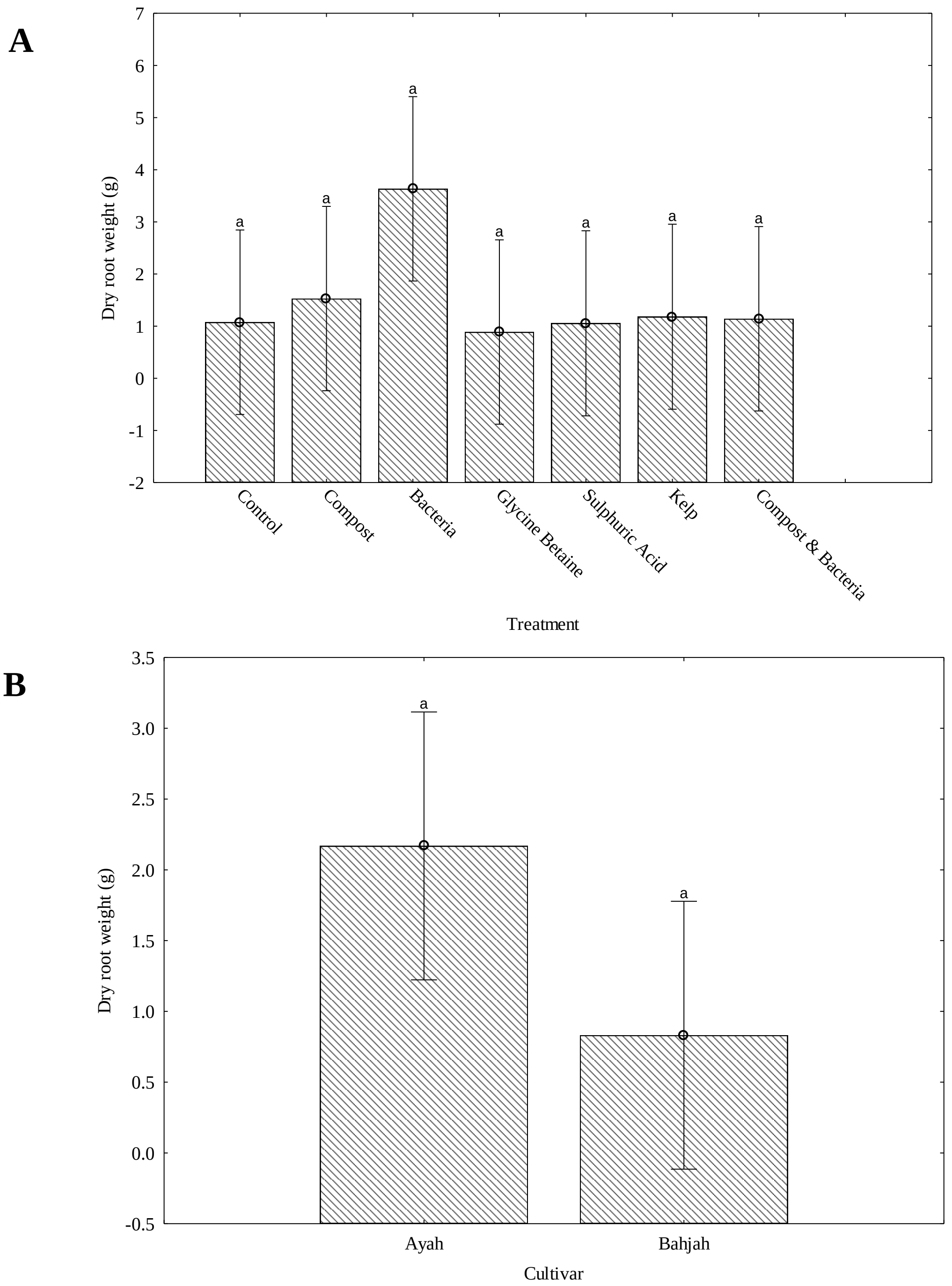
[z] p-values in printed in bold is significant at the 5% confidence level

Fig. 9. Plant dry shoot weight (g) of two determinate tomato cultivars ‘Ayah’ and ‘Bahjah’ as measured at harvest on 25 January 2014 after being cultivated with standard fertigation and 3 g.L^{-1} NaCl from transplanting, whilst being subjected to six biostimulant treatments to alleviate salinity stress.



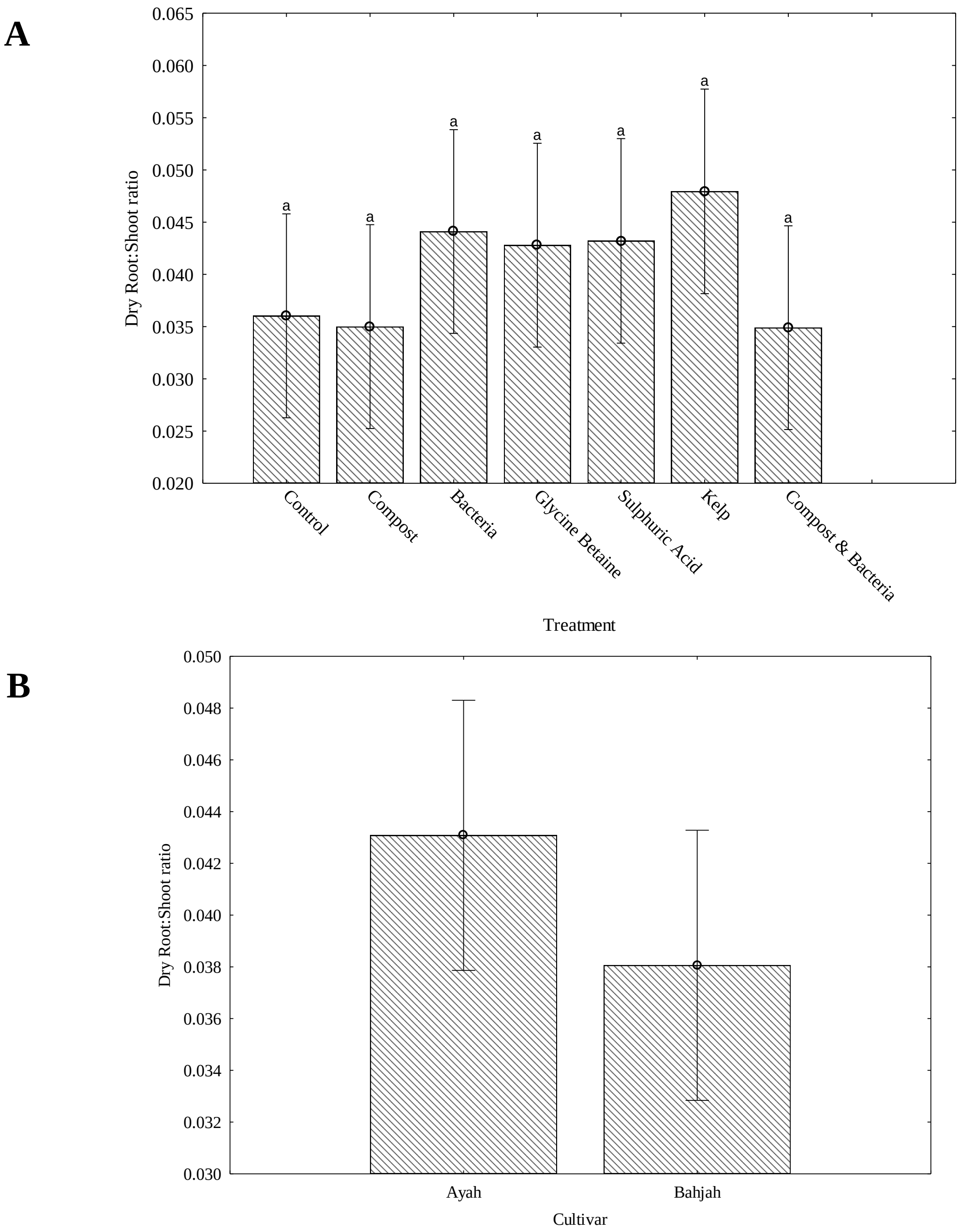
Fresh root weight	F Value	Pr>F
Block	0.77	0.6725
Treatment	1.03	0.4067
Cultivar	1.01	0.3175
Treatment*Cultivar	0.95	0.4584

Fig. 10. Plant fresh root weight (g) of two determinate tomato cultivars ‘Ayah’ and ‘Bahjah’ grown with standard fertigation and 3g.L^{-1} NaCl from transplanting to harvest, whilst subjected to six biostimulant treatments to alleviate salinity stress as measured at harvest on 25 January 2014.



Dry root weight	F Value	Pr>F
Block	1.03	0.4218
Treatment	1.15	0.3355
Cultivar	3.9	0.0502
Treatment*Cultivar	0.78	0.5907

Fig. 11. Plant dry root weight (g) of two determinate tomato cultivars ‘Ayah’ and ‘Bahjah’ as measured at harvest on 25 January 2014 after being cultivated with standard fertigation and 3 g.L^{-1} NaCl from transplanting, whilst being subjected to six biostimulant treatments to alleviate salinity stress.



Dry root: shoot ratio	F Value	Pr>F
Treatment	1.1077	0.3604
Cultivar	1.8058	0.1810
Treatment*Cultivar	0.6054	0.7257

Fig. 12. Plant dry root: shoot ratio at harvest of two determinate tomato cultivars ‘Ayah’ and ‘Bahjah’ grown with standard fertigation and 3g.L^{-1} NaCl from transplanting to harvest, whilst subjected to six biostimulant treatments to alleviate salinity stress as measured after sun drying after harvest.

Paper 5: Evaluating biostimulant efficacy to ameliorate salinity effect on two banana cultivars in the Jordan Valley

ABSTRACT

Four different biostimulant approaches (compost, glycine betaine, kelp and sulphuric acid) were assessed for their efficacy to enhance the vegetative growth of two determinate banana cultivars, 'Grand Nain' and 'Paz', when grown under saline production conditions, closely resembling that of the Jordan valley. Trials were carried out from 14 February 2014 to 26 April 2014. Compost, Kelp and Sulphuric acid as ameliorants were soil-applied, whilst the Glycine Betaine treatment was foliar-sprayed, either weekly or fortnightly. Salinity was induced by the addition of 3 g.L^{-1} NaCl to the daily applied, standard fertigation which resulted in an electrical conductivity (EC) of 3.9-5 mS.cm^{-1}. Growth parameters to assess the plant response to salinity included plant height as well as leaf number over time and at harvest, fresh and dry root and shoot weight, and also widest leaf width as an estimation of leaf area. Results indicated that both the compost treatment and the glycine betaine spray treatment, where an application was made every 14 days, proved to be the best two soil ameliorants. The Kelp treatment had a beneficial effect on roots, whereas the Glycine betaine treatment (applied on a weekly basis) and the treatment that combined the compost and glycine betaine treatment (once every 14 days) promoted vegetative growth above ground, while also impacting positively on dry root weight. However, when glycine betaine was used in combination with compost, the amelioration effect of compost alone was somewhat reduced. No beneficial effect of Sulphuric acid as ameliorant under saline conditions could be observed. 'Paz' showed greater tolerance than 'Grand Nain' to salinity. This study identified the treatments Compost and Glycine betaine as the best soil ameliorant for the banana cultivars 'Paz' and 'Grand Nain' to under saline soil growing conditions. More in depth research which should include the full phenological cycle up to fruiting, in addition to the evaluation of further treatment combinations, as well as the inclusion of more banana cultivars, is required to confirm results from this study and before protocols can be recommended for the implementation of suitable amelioration practices that can assist in managing salinity as a worldwide production challenge.

ADDITIONAL INDEX WORDS.

Abiotic stress, Compost, Glycine betaine, "Grand Nain", Kelp, "Paz", Sulphuric acid

Introduction

Salinity is an ever-present threat to crop yield and sustainable production, especially in countries where irrigation is essential to agriculture (Flowers, 2004). Globally, over 4,000,000 km^2 is estimated to be affected to by salinity to a lesser or greater extent (FAO Statistics, 2006). It has been estimated that worldwide 20 % of total cultivated and 33 % of irrigated agricultural lands are afflicted by high salinity. Furthermore, the salinized areas are increasing at a rate of 10 % annually for various reasons, including low precipitation, high surface evaporation, weathering of native rocks, irrigation with saline water, and poor cultural practices. It has been estimated that more than 50 % of the arable land would be salinized by the year 2050 (Jamil et al., 2011). Visible symptoms of salt stress on crops include: reduced growth, early leaf senescence and the appearance of chlorotic and necrotic spots on leaves (Greenway and Munns, 1980; Tester and Davenport, 2003).

Banana, a major horticultural crop worldwide, is planted in more than 120 countries with an annual global production estimated at 117.9 million metric tons in 2015 (FAO STAT, 2015). Banana provide food for millions of people and rank fourth after rice, wheat and maize in terms of food crops (De Langhe et al. 2009). Reference to most commercial banana production are to systems in the humid tropics, where frequent rainfall is experienced year-round, yet there are also significant areas of production in regions with more subtropical or even Mediterranean climates (Stover and Simmonds 1987). In these areas, supplemental irrigation is required during the dry season (Israeli, 2000), which increases the risk of introduced salinity, amongst others, due to the high nutritional needs of banana and the high use of fertilizers through the irrigation system.

Banana cultivars are generally considered to be salt-sensitive. It is known that the salinity threshold for banana plants is about 1 dS m^{-1} (Israeli et al., 1986). Higher salinity levels result in yield reduction, where a yield reduction of about 50 % was reported when the electrical conductivity of the irrigation water was raised from 1 dS.m^{-1} to 7 dS.m^{-1}. Similar findings were also reported by Yano-Melo et al. (2003) in a study where arbuscular mycorrhizal fungi (AMF) was shown to increase tolerance to soil salinity of banana plants (*Musa* sp. cv. Pacovan). Salt tolerance of inoculated plants were observed by recording increased leaf number and plant height, along with a general higher nutrient content and growth rates. When Abd El-Latef et al. (2007) compared the two banana varieties ‘Grand Nain’ and ‘Williams’ for their salinity tolerance, in most cases ‘Grand Nain’ was reported to be more resistant, with significantly higher values of both vegetative growth and chemical composition than ‘Williams’.

Soil amelioration through the application of organic compost and other biological products have been used successfully worldwide as part of a strategy to combat abiotic stress resulting from draught and salinity. In a study by Lashari et al. (2013) on wheat grown on saline soils in China, production was increased in both the first and second years when compared to the control, after the use of biochar poultry manure compost. Furthermore, there was a decrease in soil salinity, soil pH and bulk density of the soil. In another study in China by Wang et al. (2014), four organic amendments were used as treatments in addition to the control. The treatments included green waste compost, sedge peat, furfural residue and a mixture in a ratio of 1:1:1 by volume of all three treatments. Results showed that the green waste compost produced the best results with regard to reducing the bulk density of the soil. However, in the combined treatment, the bulk density, electrical conductivity (EC) and exchangeable sodium percentage (ESP) of the soil decreased by 11, 87, and 71 %, respectively, whilst the total porosity and organic carbon had increased by 25 and 96 % respectively, relative to the control treatment. It was concluded that a combination of green waste compost, sedge peat and furfural residue rather than the each amendment alone, showed significant potential for amelioration of saline soils in the coastal areas of northern China.

One approach to enhance plant tolerance to salinity may be at a metabolic level through the exogenous application of glycine betaine. Rhodes and Hanson (1993) described glycine betaine as a quaternary ammonium compound found in bacteria, cyanobacteria and algae, but also in animals and plants of several families. Hanson and Scott (1980) stated that glycine betaine accumulate in the leaves of some plants after exposure to saline and drought stress conditions. The mode of action of glycine betaine is through osmotic adjustment (Wyn Jones and Storey 1981), and also by protection of leaf plasma membrane and chloroplast thylakoid membrane (Yang et al 1996). A study by Rahman et al. (2002), on rice in Japan, reported that plants stressed with NaCl and treated with glycine betaine recorded less Na^+ concentration in their shoots than plants treated with NaCl only, but without the ameliorating effect of glycine betaine. Glycine betaine treated plants also had a higher K^+ content, however glycine betaine was ineffective to decrease damage to the roots due to salinity. Of interest is a study by Nawaz and Ashraf (2010) on maize, conducted at different growth stages, under salt stress in Pakistan. The exogenous application of glycine betaine at 0, 50 and 100 mM as a foliar spray, resulted in upregulating of the photosynthetic capacity and the activities of some antioxidant enzymes.

Seaweed extracts (Kelp), a product which have been historically used as a soil amendment, are now increasingly being recognized in modern agriculture as a low cost source of nutrient-rich biomass (Angus and Dargie, 2002; Cuomo et al., 1995). Aldworth and van

Staden (1987) found that dipping cabbage seedlings in a kelp extract from *Ecklonia maxima* reduced transplant shock and increased their biomass by 33 % compared to the control four weeks after planting. Furthermore, Abetz and Young (1983) reported that drenches with a kelp extract from *Ascophyllum nodosum* increased the curd size of cauliflower in southern Victoria. In a study conducted on tomato seedlings in Mexico, Hernández-Herrera et al. (2013) assessed the efficacy of kelp at different concentrations (0.2, 0.4, and 1.0 %) compared to the control (5ml of distilled water) to enhance a range of germination parameters such as germination percentage, index, mean time, energy and seedling vigour index, as well as and some growth indicators including that of plumule- and radical length, root- and shoot length, as well as fresh- and dry weight. Results indicated that seeds treated with kelp in the lower concentration range of 0.2 % enhanced germination through a better response in germination rate, which was associated with a lower mean germination time, a high germination index and increase germination energy. This resulted in greater seedling vigour as well as greater plumule and radicle length. A soil drench was also reported to be effective in influencing the height of the plant (up to 79 cm) than the foliar spray application (75 cm).

Sulphuric acid is also one of the oldest soil remedies to combat soil salinity and improve saline soils properties. When sulphuric acid was evaluated for its amelioration and improvement in drainage properties as well as the ability to lower the soil pH, a reaction with soluble carbonates and replacement of the exchangeable sodium with calcium was reported (Muhammad, 1990; Sharma et al., 1996). A study by Sadiq et al. (2003) on cotton in Pakistan reported that a sulphuric acid application resulted in a significant increase in germination percentage, plant population, number of bolls and yield of seed cotton than in the control, grown in saline soils. In another study on cotton in Ethiopia, Worku et al. (2016) treated the soil with a control (no gypsum and no sulphuric acid), 100 % gypsum, 100 % sulphuric acid and a gypsum and sulphuric acid combined treatment in a ratio of 1:1, on depths of both 0 - 30cm and 30-60cm. Results indicated that the application of the combined gypsum and sulphuric acid treatment improved the cotton yield significantly, in both depths. Maximum yield increases of up to 187 % was observed compared to the control, whilst a significant decrease in pH by 9.4 % was reported with the application of 50 % gypsum and 50 % H_2SO_4 acid.

The aim of this study was to evaluate the efficacy of three soil-applied ameliorants (Compost, Sulphuric acid and Kelp®) and one foliar-applied biostimulant (Glycine betaine) in improving tolerance in two widely grown, banana varieties, ‘Grand Nain’ and ‘Paz’, towards severe salinity stress as is typical of the natural, saline, silty-clay soils of the Jordan Valley.

Materials and Methods

Plant material. The two most commonly planted banana (*Musa spp.*) cultivars in the Jordan Valley, 'Grand Nain' and 'Paz', were selected for this study. Tissue culture-produced plantlets as supplied by Rahan Meristem (meristem@rahan.co.il) were received at the two to three true leaf stages, on the 22 December 2013. Plantlets were transplanted into 1.2 L plastic bags in a medium comprising of a 1:1 ratio of peat moss to coco peat. These plantlets were then kept in the Modern Technical Nursery, South Shoonah (GPS coordinates 31 52` 16.85"N, 35 37` 21.35"S) for a hardening off period of five weeks, before being transplanting on 12 February 2014, at the five to six leaf stages, into plastic pots (40x40 cm), filled with saline, silty-clay soils of the Jordan valley (Table 1). Eighty-four pots per variety were placed under a black 60 % shade netting tunnel structure for the entire duration of the trial from 14 February 2014 to 26 April 2014. Temperatures at the experiment site ranged between 24-32˚C during the day and 14-26 ˚C, during the night, with a relative humidity (% RH) varying between 40 - 70 % over the cultivation period (www.jometeo.gov.jo).

Nutrient formulation. Pots were fertigated on a daily basis with a selected fertilizer blend routinely used by banana producers worldwide. The solution contained all the nutrients required excluding the calcium. An additional tank which contained only Calcium Nitrate ($CaNO_3$) at 291.7 g.1000L^{-1} was used in combination with the fertilizer blend (Table 2).

Nutrients ratios were as follow: N: 1; P: 0.75; K: 2.6; Ca: 0.5; Mg: 0.25; S: 0.6 and the trace elements consisting of a combination of Fe, Zn, Mn, Cu, B, and Mo where the sum of all the micronutrients collectively contributed 0.19 to the formulation. Each tank contained 217g Potassium Nitrate (KNO_3), 448g Potassium Sulphate (K_2SO_4), 270 g Mono-Ammonium Phosphate (MAP), 256g Magnesium Sulphate ($MgSO_4$), 0.35g Copper (chelated on EDTA), 13g Iron (chelated on EDDHA), 1g Manganese (chelated on EDTA), 4g Zinc (chelated on EDTA), 1g Boric Acid (B_2O_3) and 0.05g Sodium Molybdate (NaMo) per a total of 1000L respectively. Finally, NaCl at 1.5 g.L^{-1} was added to the solution formulation in the first three tanks to achieve an EC of 3 - 4.5 mS.L^{-1}, where after the EC was gradually increased by 2.1 g.L^{-1} after the establishment phase to achieve a final EC of 5 - 5.5 mS.L^{-1}. The blend in the tank was agitated with a suitable mixer on a weekly basis to ensure homogeneity of the solution (Table 2).

Daily fertigation was distributed from the standard mixture tank, except for once a week (Fridays), when only $CaNO_3$ was provided. Fertigation rates were applied at 1000 ml of the solution per pot, daily, throughout the entire experimental period. This rate ensured a 20 %

runoff per pot during the first 30 minutes following fertigation. The EC, pH and temperature of each tank were recorded 1 hour after mixing (Table 3). In addition, the pH of the pot media, which was recorded during the 6th and the 7th week of the experiment, was found to range from 6.2 to 6.8.

Treatments. Six treatments along with the control were applied (Table 4). The control treatment consisted of the regular saline silty-clay soils of the Jordan Valley as the entire potting medium (T1), whereas the 2nd treatment (T2) included the use of the saline silty-clay soils of the Jordan Valley soils mixed with compost (ratio 1:3) as planting media (Analysis Table.5). A 3rd treatment (T3) composed of the saline silty-clay soils of the Jordan Valley as planting media, but in combination with a Green Stim™ (Lallemand, Ul., Warsaw, Poland) foliar spray at the rate of 2.5 $g.L^{-1}$ on a weekly basis. The 4th treatment (T4) included the use of the saline silty-clay soils of the Jordan Valley as potting media, supplemented with a Green Stim™ foliar application at the rate of 2.5 $g.L^{-1}$ every 14 days. The 5th treatment (T5) consisted of the saline silty-clay soils of the Jordan Valley as potting media, augmented with the application of 1 ml of KSC Sulphacide^{R} per pot, in 1000 ml of water (Timac Agro, Spain), on a bi-weekly basis. The 6th treatment (T6) entailed using the saline silty-clay soils of the Jordan Valley as potting media with additional enrichment through the application of Kelp, dissolved at a rate of 1ml in 1000ml water, per pot (Astra Industrial Complex, Dammam, Saudi Arabia), applied also on a bi-weekly basis. The last treatment (T7) consisted of a combination T2 and T4, thus where saline silty-clay soils of Jordan Valley was mixed with compost in a ratio 1:3, in combination with the use of Green Stim™ as an foliar application at the rate of 2.5 $g.L^{-1}$ every 14 days.

No pesticide or fungicide applications were required during the experiment, mainly due to the netting coverage that controlled pest infections and created microclimatic conditions which was not conducive for pathogen infection.

Data collection. Measurements of plant height (mm), leaf number and the broadest leaf width, as well as indication of the leaf area, were recorded every 14 days. In addition, fresh root (g) and shoot weights (g) were determined on termination of the trial on 26 April 2014, where after dry root (g) and shoot weights (g) were determined on 28 May 2014, following a process of sun drying.

Experimental design and statistical analysis. A randomized complete block design was used with 12 replicates per treatment, where treatment and variety were considered the two main effects. Growth parameters were analysed by repeated analyses of variance (RANOVA) using Statistica 9.0 (Stasoft, Inc., Tulsa, Oklahoma, USA). A comparison of means was done by means of a one-way ANOVA, and linear models ANOVA, using Bonferroni's LSD posthoc separation test in Enterprise guide, Statistica 13.2

Results

Plant leaf number over time. No interaction between cultivar, treatment and time (p = 0.400193) or between cultivar and treatment (p = 0.8059), was obtained (Fig. 1). However, a significant interaction between the factors Time and Treatment (p = 0.0071; Fig. 1A) as well as between the factors Time and Cultivar (p = 0.0047; Fig. 1B) was observed. Plant leaf number for all treatments increased significantly over the entire growth period, and also showed significant increases between consecutive weeks (Fig. 1A).

The highest mean plant leaf number was recorded for the Glycine Betaine treatment applied at 14 days intervals with a mean plant leaf number of 8.5 over the evaluation period. Glycine betaine applied at 7 days intervals with a mean plant leaf number of 8.1 was followed by the Compost & glycine betaine at 14 days intervals that recorded an average of 8.0 leaves, compared to the Compost treatment that reported a similar number of leaves at 8.0. The Control treatment with an average of 7.9 leaves, were comparable with that of the Kelp treatment also at 7.9 leaves, whereas the sulphuric acid scored an average of 7.8 leaves.

Final mean plant leaf number was recorded at 6.9 for 'Grand Nain' and 9.1 for 'Paz' respectively (Fig. 1B). Plant leaf number for the respective cultivars showed significant increases between the consecutive monitoring weeks (Fig. 1B).

Plant leaf number at harvest. No significant interaction (p=0.5058) between treatment and cultivar or between treatments (p = 0.4994) for final leaf number at harvest was observed (Fig. 2). However, a trend suggest the glycine betaine treatment applied every 14 days to have produced more leaves with a score of 9.7 leaves than the control and Kelp treatments with scores of 9 and 9.1 leaves respectively, but was comparable to the number of leaves produced by trees exposed to the combined Compost with 9.34 leaves and Glycine Betaine treatment with 9.41 leaves (Fig. 2A). The mean leaf number for 'Grand Nain' at 8.1 was significant lower than that recorded for 'Paz' at 10.5 (Fig. 2B).

Plant height over time. No significant interaction between treatment, cultivar and time (p = 0.5820), between time and cultivar (p = 0.7050) or between treatment and cultivar (p = 0.5234) was obtained (Fig. 3). However, a significant interaction between time and treatment (p = 0.0004 was observed (Fig. 3). Plant height for all treatments increased significantly over the entire growth period, also with significant increases between consecutive weeks (Fig. 3A).

Plants from Glycine betaine at 14 days intervals treatment achieved the highest mean plant height at 230.8 mm, but was not significantly different from the mean height of the Compost treated plants at 228.1 mm, or from that of the Glycine betaine plants treated at 7 days intervals at 224.6 mm, or from plants exposed to the combination treatment of Compost and glycine betaine at 14 days intervals, at a height of 214.7 mm. Plants treated with Kelp scored an average height of 212.3 mm, but again did not differ significantly from the previous mentioned treatments or from that of sulphuric acid at 209.8 mm or from that of the Control plants at 205.6 mm.

Final mean plant height of 212.2 mm for 'Grand Nain' and 223.4 mm for 'Paz' respectively was achieved, yet with no significant difference (p = 0.0891) between them at the 5 % confidence level (Fig. 3B). Plant heights for the respective cultivars however showed significant increases between the consecutive monitoring weeks (Fig. 3B).

Plant height at harvest. No significant (p = 0.5058) interaction between treatment and cultivar for plant height at harvest was observed (Fig. 4). The compost treatment and the two Glycine betaine treatments obtained the highest mean plant height with no significant difference between them, but they differed significantly from the Kelp, Sulphuric acid and control treatments (Fig. 4A). The mean plant height for 'Grand Nain' was recorded at 314 mm, but was not significantly different (p=0.347899) from that of 'Paz' at 322 mm (Fig. 4B).

Broadest leaf width. *13 March.* No interaction between treatment and cultivar (0.896605) for broadest leaf width was obtained on the 13 March evaluation date (Figs. 5A; B). Treatments did not affect leaf width significantly (p = 0.7375; Fig. 5A), although the mean leaf width for 'Grand Nain' was significantly higher (p < 0.000) at 154.8 mm than for 'Paz' at 138.3 mm (Fig. 5B).

27 March. No significant interaction (p = 0.2354) between treatment and cultivar was recorded for the broadest leaf width in the later evaluation date (Figs. 5 C; D). Treatment again did not influence leaf width significantly (p = 0.8398; Fig. 5C), but 'Grand Nain' still retained a significantly higher (p = 0.0025) leaf width at 205 mm compared to the leaf width of 190 mm that was recorded for 'Paz' (Fig. 5D).

Fresh and dry shoot weight. No significant interactions (p = 0.5555; p=0.5787) between treatment and cultivar were calculated for either fresh- or dry shoot weight, respectively (Figs. 6, 8). Treatments however significantly affected the mean fresh shoot weight, where the fresh shoot weight associated with the Compost treatment was significantly higher than that of plants exposed to the Sulphuric acid treatment or that of the control treatment (Fig. 6A). Dry shoot weight obtained from the Compost treatment did differ significantly from all the other treatments except from the compost and glycine betaine treatment. On the other hand compost and glycine treatment did not differ significantly from any other treatment except from the control treatment (Fig. 8A).

No significant (p= 0.2239; p=0.9506) cultivar differences were detected for either fresh or dry shoot weight for 'Grand Nain' at 664.7 or 52.4 g compared to 'Paz' at 634.1 or 52.4 g respectively (Figs. 6B; 8B).

Fresh and dry root weight. As was observed for the fresh shoot weight, no significant interaction (p = 0.4662; 0.3004) between treatment and cultivar was calculated for either fresh- or dry root weight respectively (Figs. 7, 9). The Compost treatment recorded the best fresh root weight, which was significantly higher (p < 0.0001) than that recorded for the sulphuric acid treatment, the glycine betaine treatment at applied every 14 days, or the control treatment, but comparable with that of the Glycine betaine-, Kelp- and glycine betaine-compost combination treatments (Fig. 7A). For the dry root weight, the Compost treatment scored the highest mean dry root weight, however, it was only significantly different (p=0.0081) from that of the sulphuric acid treatment, but not any of the other treatments (Fig. 9A).

Mean fresh root weight was not significant different (p = 0.6563) between cultivars, with 308.9 and 303.3 g recorded for 'Grand Nain' and 'Paz' respectively (Fig. 7B). However, results showed that 'Paz' had a significant (p = 0.0127) greater dry root weight than that recorded for 'Grand Nain' (Fig. 9B).

Fresh root: Shoot ratio. No interaction (p = 0.8860; Fig. 10) between treatment and cultivar or between either main effects 'treatment' (Fig. 10A) or 'cultivar' at 0.462 for 'Grand Nain' or 0.485 for 'Paz' (Fig. 10B) was observed for the fresh root weight: fresh shoot weight ratio.

Discussion

Production of crops over large areas of the world's arable land are in danger of being seriously limited by a number of physio-chemical constraints in the soil overall, such as salinity and sodicity, which cause significant reductions in crop yield (Rengasamy, 2010). Salinity inhibits the growth and thus the productivity of crops as a direct effect of ion toxicity (Al-Karaki, 2000), despite the ability of most plants to accumulate both sodium and chloride ions in relative high concentrations in shoot tissues when grown in saline soils (Tavakkoli et al. 2011).

The use of different types of ameliorants has attracted special attention in recent years due to their reported beneficial effects to protect against salinity stress and assist in promoting competitiveness under salinity conditions. The physical, chemical and biological properties of soil in salt-affected areas have consistently shown improvement when augmented with organic matter, leading to enhanced plant growth and development, and thus ensuring more sustainable land use and higher crop productivity (Choudhary et al., 2004; Wong et al., 2009).

Our study on banana saplings, in the early phase of establishment, confirmed the positive effects associated with the addition of organic matter when used in the remediation of saline soils, as treatments containing compost consistently promoted vegetative growth parameters (Figs. 1, 2, 3, 4, 5, and 6). In a study by Al Busaidi (2012) on banana in Oman, the best results though not significant, with respect to enhanced plant height and leaf area were obtained when mineral fertilizers were integrated with compost, rather than used in isolation. In addition, a significant increase in the number of leaves produced were reported when the plants in Oman were exposed to a combination of fertilizers and organic material, a finding that was also confirmed in our study with the banana saplings (Figs. 1, 2, 3, 4 and 5). Similarly, our results showed a consistent increase in both fresh and dry shoot and root weight in plants that received the compost treatment, when compared to the control and sulphuric acid-treated plants (Figs. 6, 7, 8 and 9). A study by Gharib et al. (2008) in Egypt also reported an increase in sweet marjoram production when adding liquid-compost in combination with a fertilizer to irrigation water. Similar results was obtained by El Naggar (2010), in a study on *Narcissus tazetta, L.* in Egypt, where the use of bio-fertilizer treatment significantly increased most of the leaf characteristics, including the number of leaves per plant, leaf length and width, along with root and leaf fresh and dry weight. Additionally, Klasman et al. (2002) stated that cut flower quality of *Lilium* plants, in terms of dry matter accumulation of the mother bulbs, stem length, number of daughter bulbs produced, was best in soil amended with rice hulls.

However, under extreme growing conditions like the Jordan Valley, with low rainfall and high temperatures, vegetative plant waste is not always readily available and the production or transport of compost pose a challenge. Under these conditions, alternative sources to combat soil salinity will be required, thus leading to the evaluation of additional products e.g. glycine betaine, kelp and sulphuric acid in this study.

The reports on the use of glycine betaine on banana for the amelioration of salinity could not be sourced, yet other reports on the efficacy of this metabolite to improve production under water-stressed conditions is well documented. In a recent study, Cirillo et al. (2016) reported on the effect of exogenous application of glycine betaine on two ornamental shrubs, *Viburnum lucidum L.* (Arrow-wood) and *Callistemon citrinus*, when fertigated with saline nutrient solution. The application of glycine betaine to salt stressed Arrow-wood increased both the apical and lateral shoot lengths, the number of leaves per plant and shoot dry biomass. Our study produced similar results (Fig. 4) where three different glycine betaine treatments improved the plant height and leaf number at harvest, in addition to improving leaf width as an indication of leaf area when compared to characteristics exhibited by control, kelp and sulphuric acid treated plants.

A study on cowpea Manaf (2016) reported that, when glycine betaine is applied exogenously, it improved both the fresh and dry shoot weight and leaf area compared to control plants that was exposed to saline conditions, but without any amelioration. In our study, glycine betaine produced favourable, comparative results, but compost-treated plants still obtained the best ranking with respect to leaf width, fresh and dry shoot weight (Figs. 5, 6 and 8). In Argentina, the exogenous application of glycine betaine was also reported to increase the dry weight of vinal *Prosopis ruscifolia* seedlings when grown under saline conditions (Miloni and Martinez, 2009).

Results on banana in our study showed a similar increase in dry shoot weigh and dry root weight for glycine betaine-treated plants, compared to control, kelp and sulphuric acid treatments (Figs. 7 and 9). Kausar et al. (2014), conducting a study on maize in Pakistan, reported the negative impact of salinity to be remediated with respect to vegetative parameters such as root- and shoot length, fresh-and dry weight of root and shoots, along with leaf number and leaf area, through the application of glycine betaine at 50 mM and 100 mM. Of interest is that glycine betaine at 100 mM was reported to yield better results on plants exposed to salinity stress compared to the treatments where 50m M were applied. Our research on banana confirmed the beneficial effects of glycine betaine (Figs. 4 and 9), even though we included only one concentration of the glycine betaine based on recommendations by the manufacturer. As an alternative to different application rates, we used two frequencies of applications which were either every 7 days or every 14 days. Findings regarding the frequencies of applications showed (Figs. 2, 4, 8 and 9) with regard to plant height and leaf number at harvest, in addition to dry weights, that more frequent glycine betaine applications exerted a negative effect on plants when compared to plants which received only one application of glycine betaine every 14 days.

Kelp soil application is general considered to have a positive effect on plant growth under normal soil conditions. This is most probably due to the presence of mixture of organic compounds, possibly including cytokinin and auxin growth regulators, previously identified in the extract in kelp and all sea weed extracts (Tay et al. 1985; Lötze and Hoffman, 2016).

Mattner et al. (2013) reported the application of Kelp to significantly increase the leaf number, stem diameter and leaf area by 6 %, 10 % and 9 %, respectively, when establishing broccoli seedlings in Australia. Manaf (2016) incorporated Kelp as one of the treatments in addition to glycine betaine. In this study the use of Kelp products was reported to increase the fresh and dry shoot weight and leaf area when compared to the control treatment that was exposed to saline conditions with any remediation. This finding is similar to our results on banana, where kelp improved leaf width, and also fresh and dry shoot weight. Kelp, proved to yield better, though not statistically different from that of the control, sulphuric acid and compost treatments with regards to leaf width, while in fresh and dry shoot weight the kelp treatment only outperformed the control and sulphuric acid-treated plants (Figs. 5, 6 and 8). Thus, our results confirmed (Figs. 1, 2, 3, 4, 6, 7, 8, and 9) that glycine betaine treatment combinations produced better results than kelp alone, but not significantly so.

In a study on durum wheat in Morocco, Latique et al. (2014) confirmed previous reports of an increase in shoot length, fresh shoot weight and dry shoot weight when treating with kelp, even though kelp as a treatment scored lower than compost and the other three glycine betaine treatments. Our study confirmed these results where improvement of plant height and fresh and dry shoot weight was recorded with the Kelp treatment compared to the control or plants treated with sulphuric acid, even though it was not significant (Figs. 3, 4, 6 and 8). When Mostafa (2015) studied fennel production under saline condition in Egypt, an increase in plant height, fresh and dry shoot weight, and fresh root weight was obtained when the plants were treated with kelp. The current study on banana resulted also in an increased leaf width, fresh and dry shoot weight, and fresh and dry root weight with kelp treatment, with increased performance compared to the control and sulphuric acid treatments, in all criteria, although often not significant (Figs. 5, 6, 7, 8, and 9). With regard to leaf width and fresh and dry root weight, the kelp treatment in our study out performed some glycine betaine treatments (Fig. 5, 7 and 9).

Sulphuric acid, probably the most well-known and used chemical ameliorant for salinity in our study, unexpectedly did not produce results which differed significantly from the control in any of the results. In some instances, it even appeared to be detrimental to plant growth where it scored lower than the control as was the case in plant height, leaf width, fresh and dry root and shoot weight (Figs. 4-9). This negative results could be partly due to the high electrical conductivity of the product that was not suitable for the soil type, as already comparatively high electrical conductivity values existed in the fertigation solution (Table 3).

Reports by Adnan et al. (2014) a research that was done on wheat in Pakistan, reported that application of sulphuric acid resulted in significantly improving plant height, number of tillers, photosynthetic rate, transpiration rate and stomata conductance, when compared to plants treated with gypsum, polyvinyl alcohol and citric acid. Zia et al. (2007) in Pakistan conducted a study where the effect of a four crop rotation system of rice, wheat, sesbania and rice-berseem when used in combination with the soil ameliorants, sulphuric acid and gypsum, was evaluated to determine the best production practise suited for saline soils. In this study, improved yields in both wheat and rice crops were obtained based on inorganic amendments rather than the crop rotation. This finding, which dismissed the bias towards organic remediation being considered to be a more successful strategy, however did not apply to our study where sulphuric acid did not offer any benefit to banana plants in terms of enhanced growth and development.

Conclusion

Results on banana from our study lead us to conclude that both the Compost treatmentand the treatment that contained a combination of Glycine betaine and Compost was the most successful to enhance plant growth in banana under the saline conditions. Despite of the different modes of action and target organs (root and/or leaf) of the treatments, growth below and above ground components (dry root and shoot weight) were affected similarly by each treatment. An increase or decrease in shoot growth were thus never directly due to the opposite reaction in root growth as reported by Shereni (2018) who applied various biostimulants on young, non-bearing citrus trees, where a synergistic effect of the treatment on the whole plant was evident.

In this study, despite evident trends, results were not always significant at the 5 % confidence level. Therefore, additional confirmation and validation of the results obtained in this study is required. A study in future should include the wider application rate of the already selected ameliorants, in addition to including more or less frequencies of applications and other types of ameliorants not yet tested on banana, in order to broaden our current understanding of the role and efficacy of ameliorants to increase the production capacity of banana under saline conditions. Furthermore, the trial period should be extended to include harvest data and to take account of more than one season, as the current trends may then produce more tangible and clear results, which could be used to identify treatments suitable to manage banana production under saline conditions in a sustainable manner over many seasons.

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Tables and Figures

Table 1. The physical and chemical properties of native Jordan Valley soil samples as was used as planting medium when assessing the tolerance of the two banana varieties, ‘Grand Nain’ and ‘Baz’, to salinity.

Potting Soil Characteristics	pH^w	EC^x	%N	P (mg.L^{-1})	K (mg.L^{-1})	% $CaCO_3$	Exch Ca^y	Na %^{z}	Cl (mg.L^{-1})
	7.9	2.3	0.3	17.7	219. 5	30	0.04	6.1	110

^{w}Paste extract; ^{x} Electrical Conductivity as dS.m^{-1}, paste extract; ^{y} Exchangeable Ca, meq.100g^{-1}; ^{z}ESP % (Exchangeable Sodium Percentage)

Table 2. The fertigation solution nutrient composition per 1000 L as used in an experiment when assessing the efficacy of a range of soil ameliorants on the response two banana varieties, ‘Grand Nain’ and ‘Paz’ to salinity.

Concentration	MAP	$CaNO_3$	KNO_3	K_2SO_4	$MgSO_4$	Cu EDTA	Fe EDDHA	Zn EDTA	Mn EDTA	B_2O_3	NaMo
g.1000L^{-1}	270	291.7	217	448	461.5	0.5	8.5	1.2	1.2	1	0.05

MAP: Mono-ammonium Phosphate; KNO_3: Potassium Nitrate; AN: Ammonium Nitrate; $MgSO_4$: Magnesium Sulphate; B_2O_3: Boric acid; NaMo: Sodium Molybdate; $CaNO_3$: Calcium Nitrate

Table 3. Electrical conductivity (EC; mS.L^{-1}) and pH values of the fertigation solution in the 1000L tanks (n = 6), following 1 hour of mixing used in a trial assessing the efficacy of a range of soil ameliorants on the response two banana varieties, ‘Grand Nain’ and ‘Paz’ to salinity.

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Tank Number	EC (mS.L^{-1})	pH
1	5.52	6.82
2	3.95	6.29
3	4.11	6.31
4	3.98	6.27
5	4.05	6.28
6	5.54	6.29

Table 4. The treatment description, with the application rate and timing of the various soil ameliorants, as used in a study which evaluated the response of two banana varieties, ‘Grand Nain’ and ‘Paz’ to a range to these soil ameliorants within a saline environment.

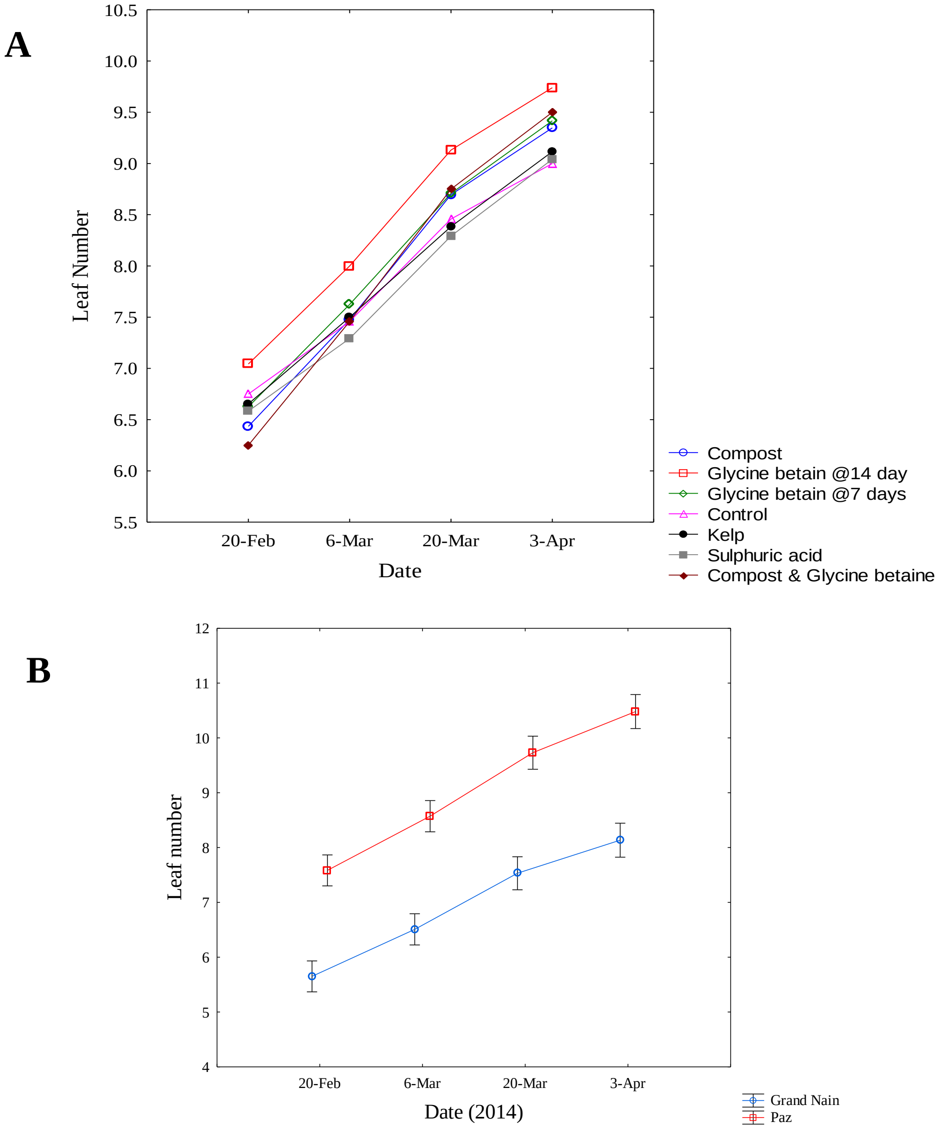
Treatment code	Treatment description	Application rate	Timing of application
T1	Control (Regular Jordan Valley soil)	-	-
T2	Regular Jordan Valley soil + Compost	Soil mixture (ratio of 1:3)	at planting
T3	Regular Jordan Valley soil + Green Stim^{TM}	Soil mixture 1g.pot^{-1}	every 7 days
T4	Regular Jordan Valley soil + Green Stim^{TM}	Foliar application (2.5g.L^{-1})	every 14 days
T5	Regular Jordan Valley soil + KSC Sulphacide soil	Soil application(1ml.L^{-1}.pot^{-1})	every 14 days
T6	Regular Jordan Valley soil + Kelp soil appl.	Soil application(1ml.L^{-1}.pot^{-1})	every 14 days
T7	Regular Jordan Valley soil + Compost 1:3 + Green Stim^{TM}	Soil mixture (1g.pot^{-1})	every 14 days

Table 5. The chemical analysis of the compost used as an amelioration treatment when mixed with the normal Jordan valley soil at the ratio of 1:3 and used as media for planting banana plants in a salinity study.

Parameter	Value and unit
Organic Matter ($^{w}/_{v}$)	88.2 %
pH	5.5
Density	243 kg.m^{-3}
Chloride	67.3 ppm^{z}
Phosphorous	4.2 ppm
Potassium	62.5 ppm
Magnesium	0.5 ppm
Calcium	0.7 ppm
Sodium	23 ppm
Electrical conductivity (EC)	0.71 dS. L^{-1}

^{z} ppm: parts per million

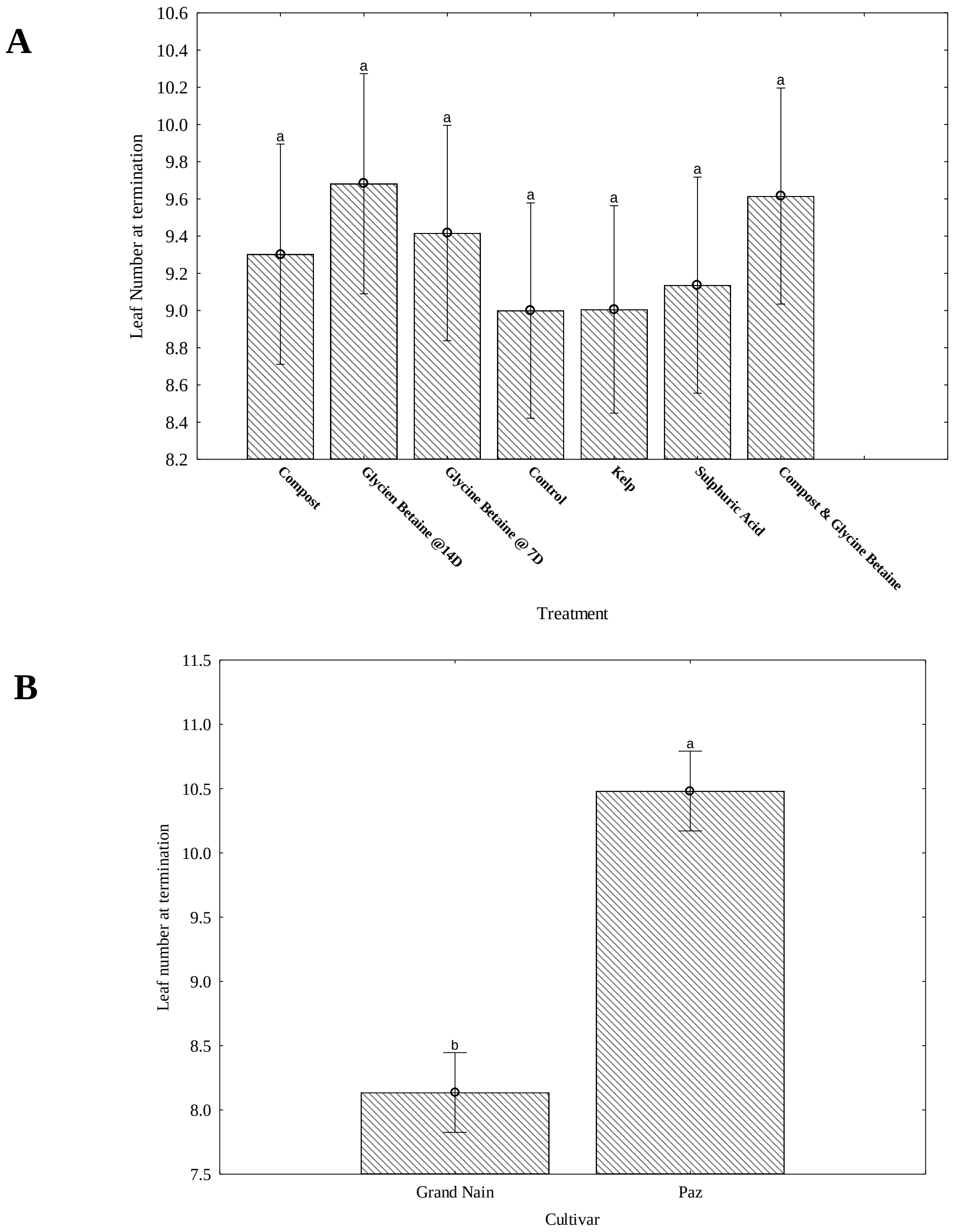
Figures



Plant leaf number	F Value	Pr>F
Intercept	6568.106	<.0001
Treatment	0.608	0.7232
Cultivar	**116.295**	**<.0001**
Treatment*Cultivar	0.502	0.8058
Time	**790.916**	**<.0001**
Time*treatment	**2.042**	**0.0071**
Time*Cultivar	**4.387**	**0.0046**[z]
Time*Treatment*Cultivar	1.051	0.4001

[z] p-values in printed in bold is significant at the 5% confidence level

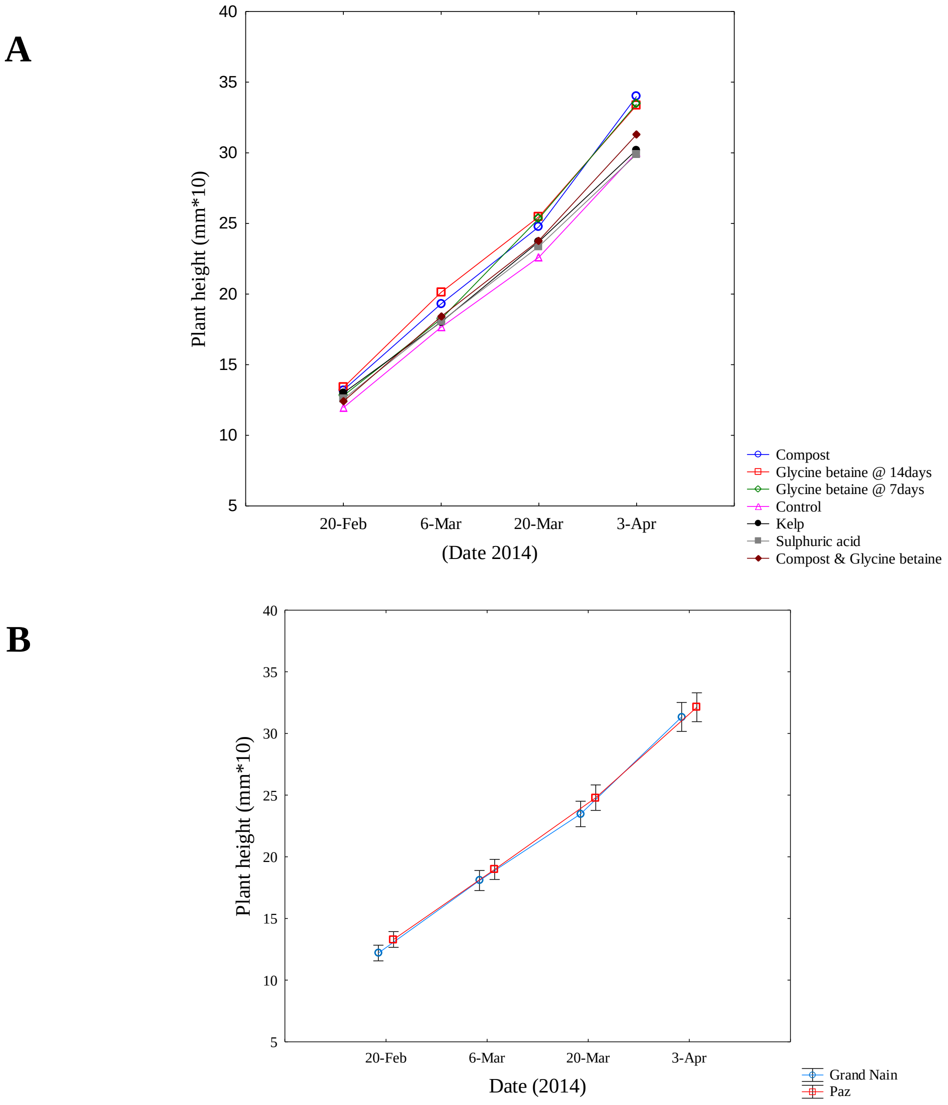
Fig. 1. Plant leaf number as recorded as part of an evaluation (Feb–Apr 2014) of two determinate banana cultivars 'Grand Nain' and 'Paz' (B) grown with standard fertigation and an additional 3 g.L^{-1} NaCl from transplanting to harvest, whilst subjected to six biostimulant treatments (A) to alleviate salinity stress.



Plant leaf number	F Value	Pr>F
Treatment	2.707	0.4993
Cultivar	**0.887**	**<.0001**[z]
Treatment*Cultivar	0.887	0.5057

[z]p-values in printed in bold is significant at the 5% confidence level

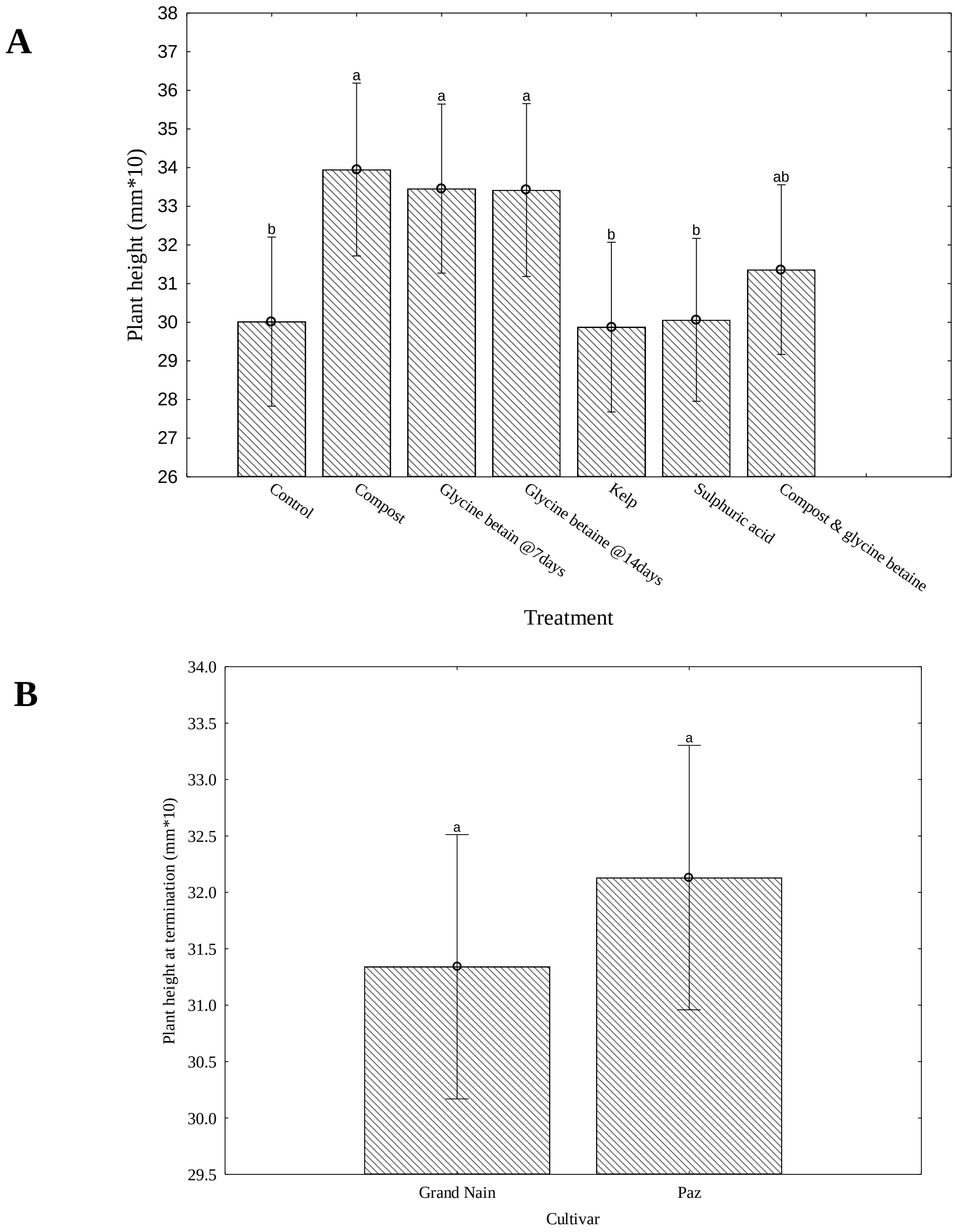
Fig. 2. Plant leaf number of two determinate banana cultivars ‘Grand Nain’ and ‘Paz’ (B) grown with standard fertigation and 3 g.L^{-1} NaCl from transplanting to harvest, whilst subjected to six biostimulant treatments (A) to alleviate salinity stress as evaluated on 26 April 2014.



Plant height	F Value	Pr>F
Intercept	5255.649	<.0001
Treatment	1.542	0.1679
Cultivar	2.927	0.0891
Treatment*Cultivar	0.863	0.5233
Time	2249.716	<.0001
Time*treatment	**2.571**	**0.0004**[z]
Time*Cultivar	0.468	0.7049
Time*Treatment*Cultivar	0.897	0.5819

[z] p-values in printed in bold is significant at the 5% confidence level

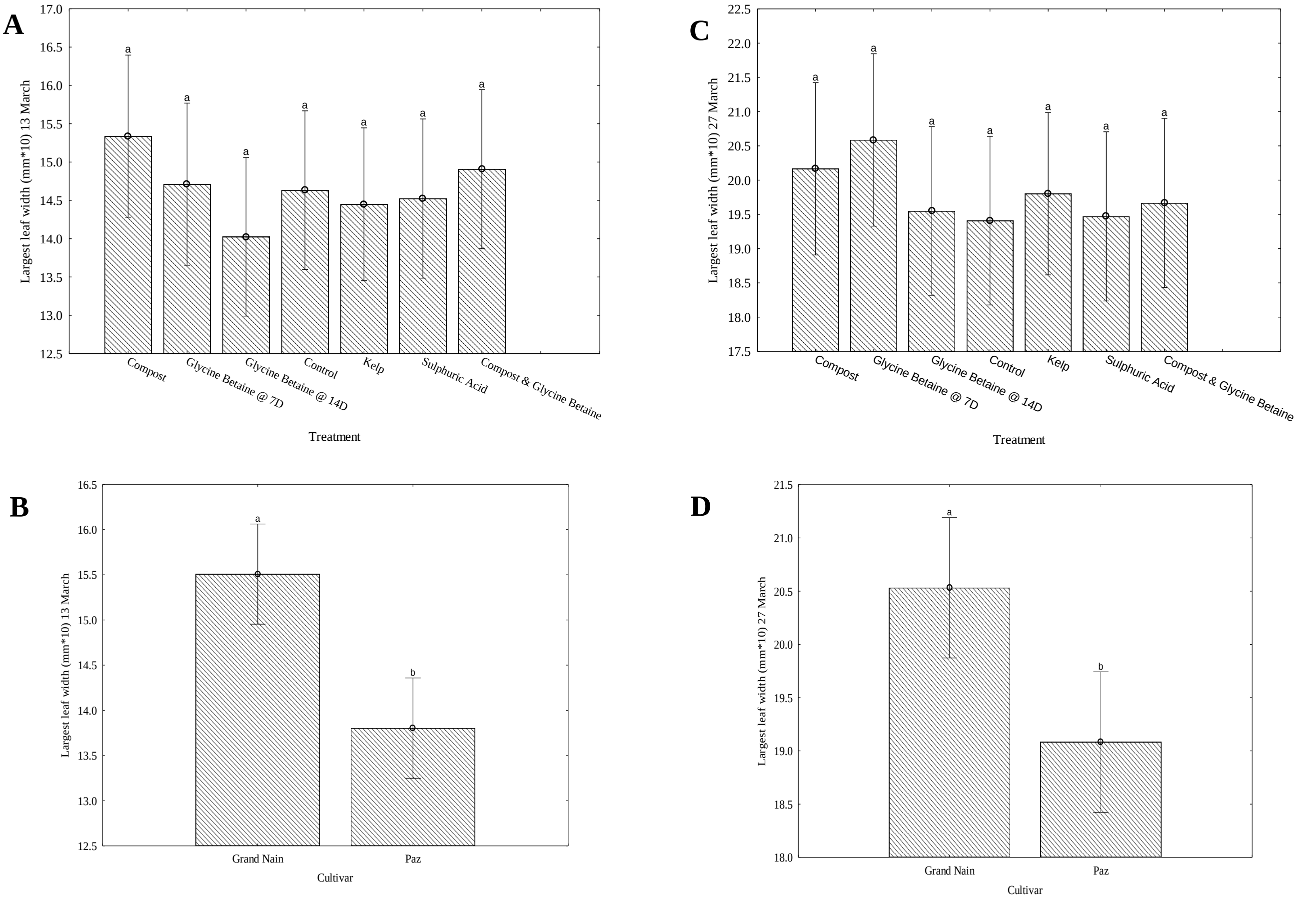
Fig. 3. Plant height (mm*10) as recorded as part of an evaluation (Feb–Apr 2014) of two determinate banana cultivars ‘Grand Nain’ and ‘Paz’ (B) grown with standard fertigation and an additional 3 g.L^{-1} NaCl from transplanting to harvest, whilst subjected to six biostimulant treatments (A) to alleviate salinity stress.



Plant height	F Value	Pr>F
Treatment	**2.707**	**0.0158**^{z}
Cultivar	0.887	0.3478
Treatment*Cultivar	0.887	0.5057

^{z}p-values in printed in bold is significant at the 5% confidence level

Fig. 4. Plant height (mm*10) of two determinate banana cultivars ‘Grand Nain’ and ‘Paz’ (B) as recorded at harvest (26 April 2014), after being cultivated under conditions of standard fertigation, but with an additional 3 g.L^{-1} NaCl, whilst subjected to six biostimulant treatments (A) to alleviate salinity stress.

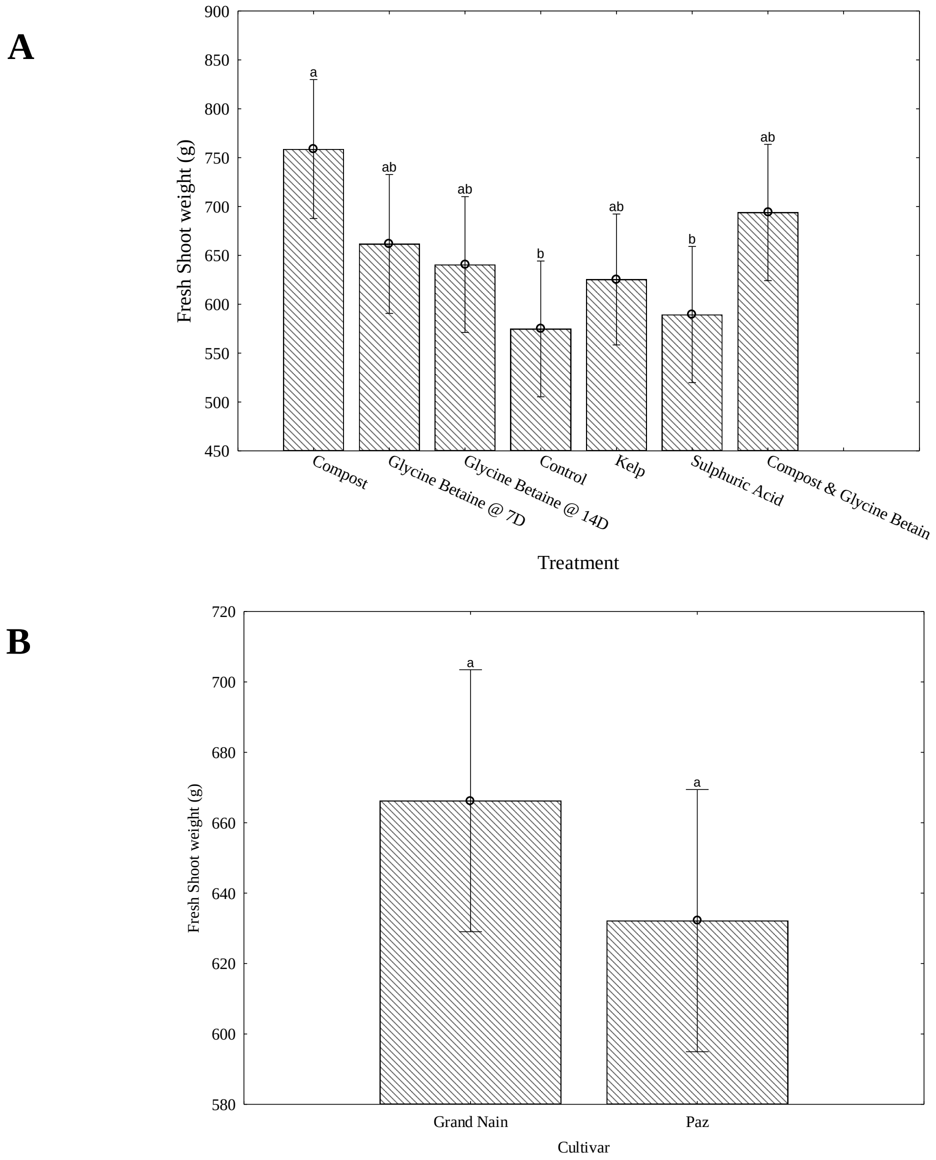


Leaf width (13 March)	F Value	Pr>F
Treatment	0.591	0.7375
Cultivar	**18.429**	**0.0003^z**
Treatment*Cultivar	0.371	0.8966

Leaf width (27 March)	F Value	Pr>F
Treatment	0.456	0.8397
Cultivar	**9.431**	**0.0025^z**
Treatment*Cultivar	1.357	0.2353

^{z}p-values in printed in bold is significant at the 5% confidence level

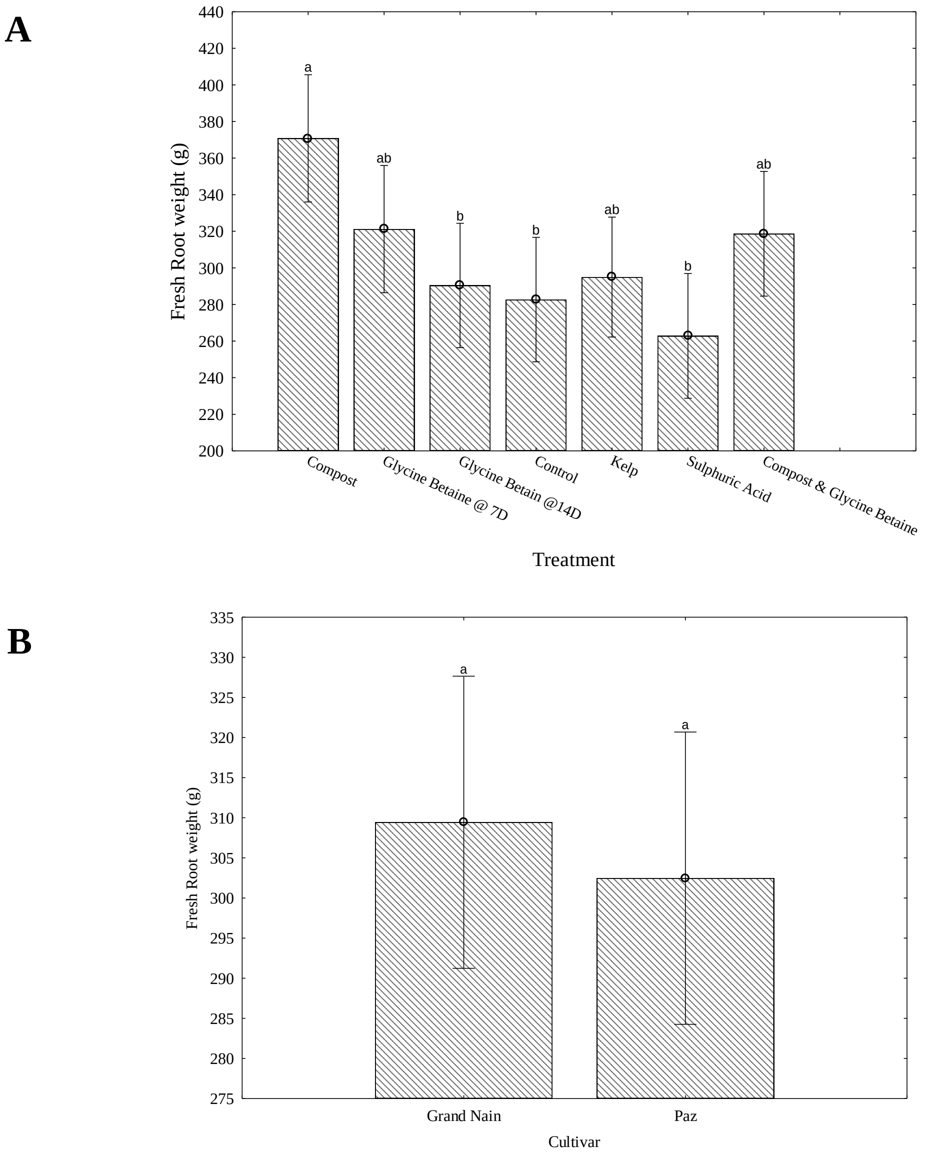
Fig. 5. Largest leaf width (mm*10) of two determinate banana cultivars ‘Grand Nain’ and ‘Paz’ (B; D) as recorded on 13 March and 27 March 2014, after being cultivated under conditions of standard fertigation, but with an additional 3 g.L^{-1} NaCl, from transplanting to harvest, whilst subjected to six biostimulant treatments (A; C) to alleviate salinity stress.



Fresh shoot weight	F Value	Pr>F
Treatment	**4.05**	**0.0009**^{z}
Cultivar	1.49	0.2239
Treatment*Cultivar	0.82	0.5555

^{z}p-values in printed in bold is significant at the 5% confidence level

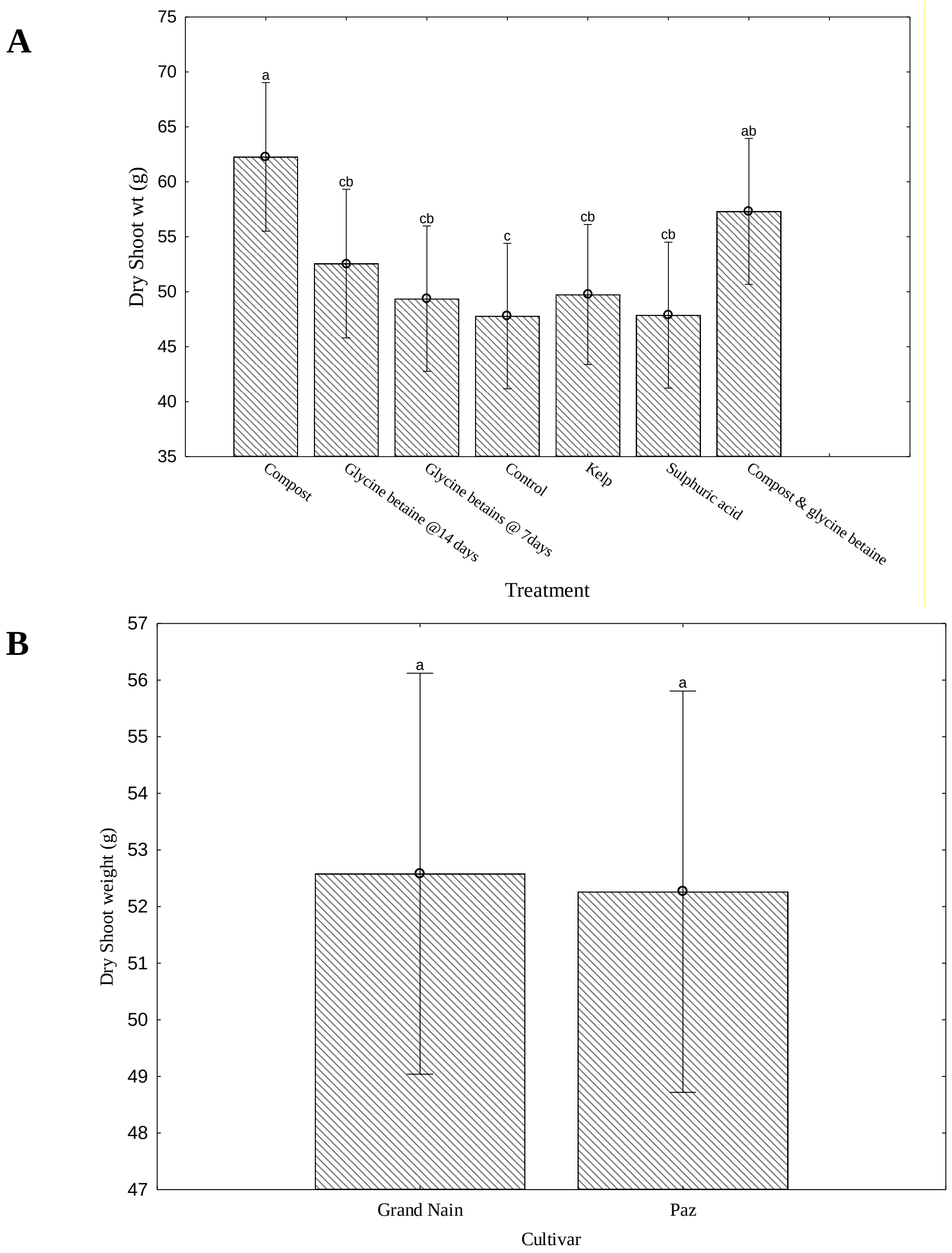
Fig. 6. Fresh shoot weight (g) of two determinate banana cultivars ‘Grand Nain’ and ‘Paz’ (B)as recorded at harvest (26 April 2014), after being cultivated under conditions of standard fertigation, but with an additional 3 g.L^{-1} NaCl, from transplanting to harvest, whilst subjected to six biostimulant treatments (A) to alleviate salinity stress.



Fresh root weight	F Value	Pr>F
Treatment	**6.18**	**<.0001**^{z}
Cultivar	0.2	0.6563^{y}
Treatment*Cultivar	0.95	0.4662

^{z}p-values in printed in bold is significant at the 5% confidence level

Fig. 7. Fresh root weight (g) of two determinate banana cultivars ‘Grand Nain’ and ‘Paz’ (B) as recorded at harvest (26 April 2014), after being cultivated under conditions of standard fertigation, but with an 3 g.L^{-1} NaCl, from transplanting to harvest, whilst subjected to six biostimulant treatments (A), to alleviate salinity stress.

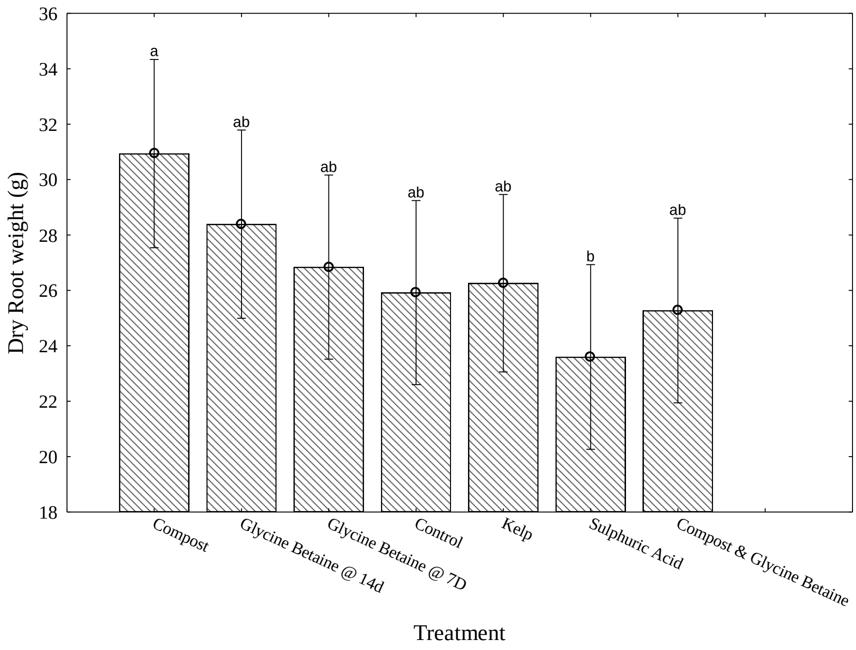


Dry shoot weight	F Value	Pr>F
Treatment	**2.6**	**0.0190**^{z}
Cultivar	0.016	0.9006
Treatment*Cultivar	0.582	0.7442

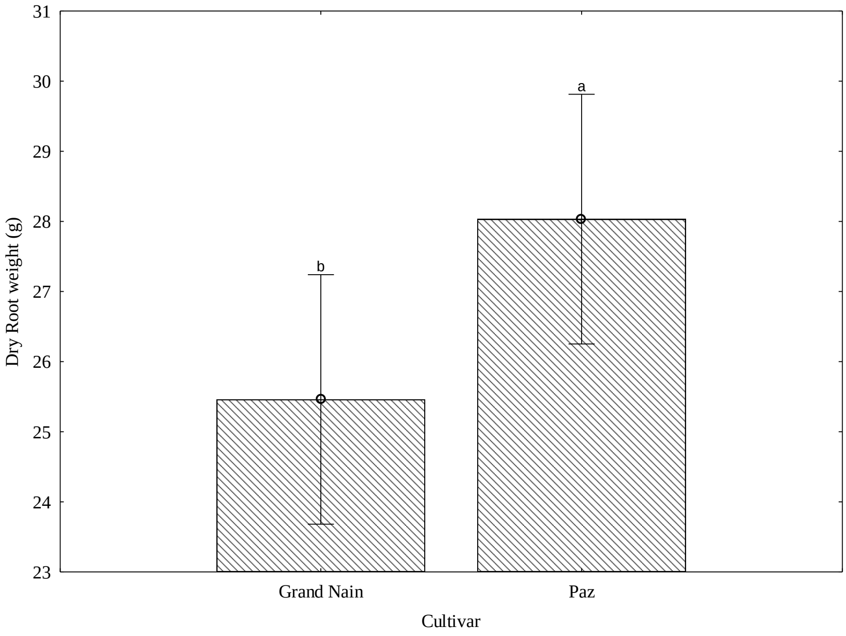
^{z}p-values in printed in bold is significant at the 5% confidence level

Fig. 8. Dry shoot weight (g) as recorded on 28 May 2014 of two determinate banana cultivars ‘Grand Nain’ and ‘Paz’ (B) grown under standard fertigation, but with an additional 3 g.L^{-1} NaCl from transplanting to harvest, whilst subjected to six biostimulant treatments (A) to alleviate salinity stress.

A



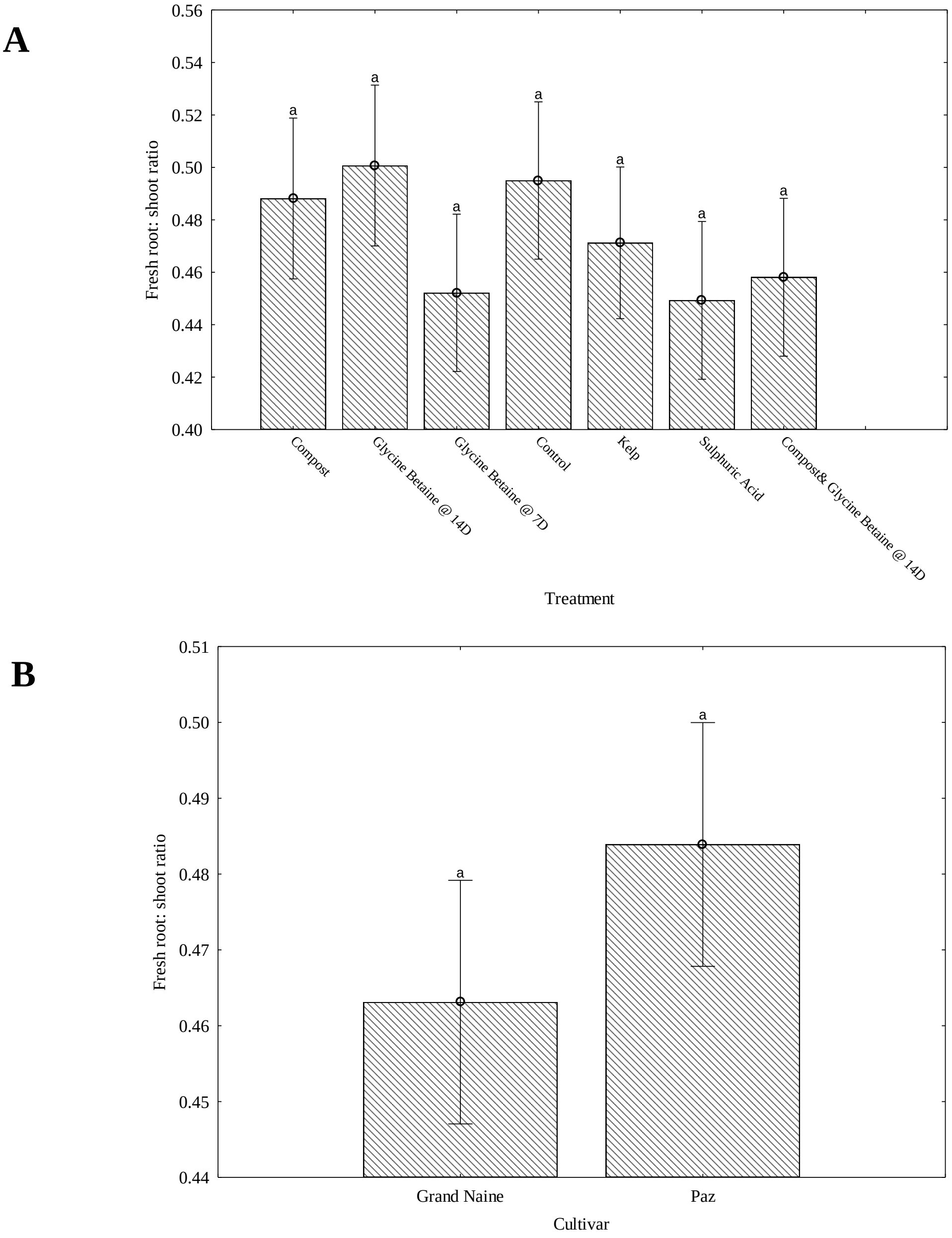
B



Dry root weight	F Value	Pr>F
Treatment	**3.03**	**0.0081**
Cultivar	**6.37**	**0.0127**^{z}
Treatment*Cultivar	1.22	0.3004

^{z}p-values in printed in bold is significant at the 5% confidence level

Fig. 9. Dry root weight (g) as recorded on 28 May 2014 of two determinate banana cultivars ‘Grand Nain’ and ‘Paz’ (B), grown under standard fertigation, but with an additional 3g.L^{-1} NaCl, from transplanting to harvest, whilst subjected to six biostimulant treatments (A) to alleviate salinity stress.



Plant leaf number	F Value	Pr>F
Treatment	0.01061	0.0813
Cultivar	0.01808	0.0725
Treatment*Cultivar	**0.00214**	**0.3870**[z]

[z]p-values in printed in bold is significant at the 5% confidence level

Fig. 10. Plant fresh root: shoot ratio of two determinate banana cultivars ‘Grand Nain’ and ‘Paz’ (B) grown as recorded at harvest (26 April 2014), after being cultivated under standard fertigation, but with an additional 3g.L^{-1} NaCl, from transplanting to harvest, whilst subjected to six biostimulant treatments (A) to alleviate salinity stress.

General Discussion and Conclusions

Salinity is increasingly becoming a critical factor limiting agricultural production worldwide. This is true especially for the region of the Middle East, but particularly so for Jordan where salinity amelioration has become an integral part of horticultural practises that are implemented on a seasonal, if not monthly basis. Yet, the areas with affected soils continues to increase annually due to the constant extension of irrigation to new areas (Patel et al., 2011). The rate of salinization accelerates to such an extent that it is estimated that globally 50% of the arable lands would be salinized by 2050 (Jamil et al., 2011).

In Paper 1 it is aimed to provide an overview on the significant research effort has been invested world-wide in attaining a better understanding of salinity. This range from studying plant responses to salinity, the screening of different cultivars for their tolerance to salinity, as well as ongoing research in plant genetic engineering, in addition to studying the role ameliorants play to provide coping mechanisms to plants under saline soil conditions (Bohnert et al., 2001). Still, more research is required to elucidate the mechanisms by which ameliorants deliver tolerance in crops to salinity, in addition to studies that should focus on showing the efficacies of these ameliorants alone or when used in combination to ensure the sustainable production of important crops grown in areas challenged by salinity.

Our study focused on the effect of salinity on the vegetative growth traits of two major crops grown in Jordan, namely banana and tomato. The tolerance to salinity of different cultivars was compared, where after the study was extended to evaluate the efficacy of various ameliorants, either alone or in combination, for their ability to provide tolerance to salinity to selected cultivars of the two crops.

In the first research chapter (Paper 2), the difference in salinity tolerance between two banana cultivars, ‘Grand Nain’ and ‘Paz’ (a selection of ‘Williams’), was assessed. Plants were grown in pots for a period of six weeks, for both a winter and summer planting, under five increasing levels of salinity which ranged from 1-5 $g.L^{-1}$ NaCl. For both plantings, the plant height and weekly leaf number showed a significant decrease with increasing salt concentration. Although cultivar differences was not evident in all cases, ‘Grand Nain’ consistently obtained better scores than ‘Paz’. Results from our study was supported by findings of Abd El-Latif et al. (2007) were also in both plantings, the fresh weights of shoots and roots decreased significantly with an increase in salt concentration, with ‘Grand Nain’ also outperforming ‘Paz’, although not significantly so in most instances.

In the second research chapter (Paper 3) a similar experimental design than that of the first experiment was followed, also for both a summer and winter planting, over a six-week period, but with the study conducted this time on five, well-known cultivars of tomato in the Jordan valley, namely ‘Alam’, ‘Majd’, ‘Asalah’, ‘Ayah’ and ‘Bahjah’. Recording of mean weekly plant height and leaf number both showed a consistent, significant decline in scores with an increase in NaCl concentration for both plantings. Significance differences in the cultivar performances for these parameters were evident, with ‘Ayah’ and ‘Alam’ being the most vigorous, followed by ‘Majd’, with ‘Asalah’ and ‘Bahjah’ being the most susceptible to salinity. When considering the root and shoots fresh weights for both plantings, along with the dry root and shoot weights for the winter planting, again an increase in NaCl concentration significantly affected these growth parameters, similar to findings reported by Rui et al. (2009) and Memon et al. (2010).

In the third research chapter (Paper 4) the efficacy of five biostimulants (compost, *Bacillus subtilis*, glycine betaine, kelp and sulphuric acid) was assessed for their ability to ameliorate the effect of salinity on two tomato cultivars (‘Ayah’ and ‘Bahjah’) commonly grown in the Jordan valley, from transplanting through to harvest.

Plant leaf number as recorded over time and at harvest equally benefitted most from the compost treatment as well as the compost and bacteria treatments which scored the highest leaf number, compared to the glycine betaine, bacteria, kelp and sulphuric acid treatments. With regard to plant leaf number ‘Ayah’ consistently outperformed ‘Bahjah’, similar to results reported on chickpea in a study by Badar et al. (2015). When considering plant height over time and at harvest, the compost treatment was again most successful in assisting plants to cope with salinity stress, with ‘Ayah’ being more successful than ‘Bahjah’ to achieve a higher plant height. Leaf width, a criteria that was used to estimate leaf area, showed a significance difference between treatments and cultivars, with the compost treatment exhibiting the highest leaf width. Similar to that reported by Adebayo et al. (2013), ‘Ayah’ generally produced wider leaves than ‘Bahjah’ under these saline conditions. As for the vegetative parameters of fresh and dry shoot weight, the fruit number and- fruit weight criteria identified the compost treatment as being significantly better than most of the other treatments. However, when considering the fresh weight a trend, though not significantly different, was noted where the kelp treatment produced the best results, while the bacteria treatment clearly promoted dry root weight accumulation under the saline conditions created in this experiment.

With regard to root development, similar to the above ground parameters, ‘Ayah’ was again significantly more successful than ‘Bahjah’ to achieve biomass accumulation. A study on okra by Papenfus et al. (2013) identified Kelp as the most beneficial treatment, while

Mohammed and Gomaa (2012) in their study on radish reported on bacteria treatment being most beneficial.

In the fourth and final research chapter (Paper 5) a similar study as was performed on tomato was also conducted on the banana cultivars, ‘Grand Nain’ and ‘Paz’, but with some modifications. In this study glycine betaine was applied either weekly or biweekly, whilst a treatment consisting of a combination of compost and a glycine betaine application every 14 days were also included.

When considering plant leaf number increase over time and final plant leaf number at the termination of the trial, no significant difference could be established between treatments. A trend however emerged where the treatment consisting of glycine betaine applications at 14 day intervals showed potential to ameliorate salinity. In addition the glycine betaine treatment that were applied at 7-day intervals, and the compost and glycine betaine combination treatment also provided some evidence of having efficacy to reduce the negative impact of salinity, especially compared to the control and sulphuric acid treatments. ‘Paz’ recorded significantly higher number of plant leaf than ‘Grand Nain’. A very similar pattern with respect to plant height over time was noted, where again no significant difference between treatments could be achieved, but where the glycine betaine treatment applied at 14-days intervals, appeared to be most promotive to plant growth under saline conditions. The top plant height at the termination of the trial was obtained from the compost and glycine betaine treatments, where these treatments produced significantly better results that could be achieved with the kelp, sulphuric acid and control treatments. Glycine betaine treatments were also indicated when the broadest leaf width, as an indication of leaf surface area was considered, although despite a strong trend, treatments differences were not significant.

A study of Al Busaidi (2012) on banana confirmed the beneficial effects of organic material for banana production in Oman. For leaf width, the higher values scored by ‘Paz’ compared to ‘Gran Nain’ was not significant at the 5% confidence level. Observations for fresh and dry shoot weight confirmed growth performance reported above where the three treatments that contained glycine betaine were consistently more effective to ameliorate the salinity effect compared to the control, sulphuric acid and kelp treatments.

The beneficial effects of glycine betaine under conditions of stress was confirmed by a more recent study of Manaf (2016) on cowpeas in Egypt. For the parameter of shoot weight however cultivar differences were not significantly, although the trend where ‘Paz’ was shown to better adapted than ‘Grand Nain’ persisted. Fresh and dry root weights showed comparative results to that observed for shoot weight, except that it was evident that the kelp treatment provided some additional advantage to root development, so that in terms of root weight, it was comparable to the beneficial glycine betaine treatment. The promotive effect of kelp on roots is well known and was particularly confirmed under conditions of salinity for durum wheat in Morocco (Latique et al. 2014).

Salinity, more than ever before, will remain an important topic of research for the next number of decades, particularly so in the light of the eminent increase in saline agricultural lands, with the additional challenge of a predicted, continuous growth in world population elevating the urgency to provide food security. Although plant responses may differ to salinity, with some cultivars or species considered to be more tolerant than others, it is also accepted that the more vigorous the cultivar, and the stronger the root system, the more tolerant and less affected with salinity this cultivar is likely to be.

While our study addressed banana and tomato as two major crops grown under conditions of moderate to severe salinity in the Jordan Valley, other important crops for this region facing the same challenges and that may benefit from findings of this study include that cucumber, melon and different range of peppers. Future studies on these crops, especially considering amelioration alternatives, would be important as currently as little scientific data is available on salinity resistance and cost effective options for the control of salinity within this region.

Results from this study showed compost to be the best soil ameliorant to provide tolerance to salinity, yet glycine betaine as a foliar spray was also identified as a possible option to promote growth normally under saline conditions. The application of glycine betaine could be considered under conditions where salinity levels are excessively high where the cost to ameliorate soils through the addition of compost may not be a viable option. In addition, kelp as a treatment emerged as an possible ameliorant to promote the development strong root systems. Results obtained in our study using sulphuric acid or *Bacillus* were not encouraging, therefore it is suggested that for future studies different microorganisms and/or strain should be considered, such products containing Rhizobacteria. Another important consideration is that, depending on the particular crop and cultivar, no single ameliorant could be identified as being consistently superior, but rather suggested that in some cases, a combination of two ameliorants may be required. This approach is justified as the different modes of action of the various ameliorants may contribute diverse benefits to the plants under conditions of stress. It is recommended that a wider range of the ameliorants and biostimulants that are now emerging as products to enhance plant growth under conditions of stress should also be tested and compared. Such product formulations may contain humic acid (Kumar et al., 2013) or jasmonic acid (Valenzuela et al., 2016). Another approach that was missing in our study is not having access to laboratories capable to measure the glycine betaine, proline, stress related proteins and amino acids in leaf tissues during the study and before and after applications in our area, so the measurements were made on vegetative and reproductive traits only, in future studies, we should look into these kind of analysis that should give more explanations to the visual results being quantified.

The promising, yet statistically inconclusive results obtained in this study warrants more in-depth research on the topic of salinity, where other important crops of the Jordan Valley, over longer growing seasons, or considering multiple seasons should be conducted to obtain a more rigorous set data that will provide greater understanding of salinity before recommendations can be made with confidence.

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