Journal of AgriSearch 3(1): 21-25
Peer Reviewed Quarterly
ISSN : 2348-8808 (Print), 2348-8867 (Online)
http://dx.doi.org/10.21921/jas.v3i1.11403

Growth and Mineral Nutrition in Salt Stressed Guava (*Psidium guajava* L.) cv. Allahabad Safeda

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ARTICLE INFO	
Received on :	26.02.2016
Accepted on :	03.03.2016
Published online :	10.03.2016

ABSTRACT

Guava cv. Allahabad Safeda was grown in saline soils and irrigated with the best available water (EC_{IW} 2.8 dS m^{-1}). Based on chemical composition (pH- 7.1, EC_{IW}- 2.8 dS m^{-1}, Na^+- 20.04 meq l^{-1} and sodium adsorption ratio- 4.86), irrigation water was categorized as marginally saline. The soil pH_2 was mostly below 8.5 but mean electrical conductivity (EC_2) values ranged from 0.5-2 dS m^{-1} indicating moderate to high salinity in the experimental soil. After one-year of experimentation, five plants randomly selected from each treatment and the data were recorded. Plant height significantly increased (LSD 5%) with increase in salinity from 0.5 dS m^{-1} to 1.4 dS m^{-1}. A similar trend was noted with respect to stem girth. The average plant height at 0.5, 0.9 and 1.4 dS m^{-1} salinity levels was 98.3 cm, 108.3 cm and 123 cm, respectively whereas the corresponding stem girth values were 2.24 cm, 2.28 cm and 2.46 cm. At 2 dS m^{-1} salinity,however, both average plant height (94.6 cm) and stem girth (2.24 cm) significantly decreased and were found to be comparable to control (0.5 dS m^{-1}) values. Plants showed negligible Na^+ accumulation in leaves up to 1.4 dS m^{-1} salinity, but exposure to elevated salinity (2 dS m^{-1}) significantly increased leaf Na^+ (0.16% DW). These data indicated a salinity tolerance (EC_2)threshold of about 1.5 dS m^{-1} inguava cultivar Allahabad Safeda.

Keywords: Guava, growth, ionic relations, salinity

INTRODUCTION

Salinity is a major abiotic stress limiting the growth and productivity of crops throughout the world. According to a recent estimate, salinity and sodicity stresses affect the productivity of over 1100 million ha (m ha) lands worldwide (Wicke *et al*., 2011). The major constraints to plant growth in saline soils, characterized by soil saturation paste electrical conductivity (EC_e)values ⩾ 4 dS m^{-1}, include osmotic stress and specific salt effects. Salinity build-up in root zone decreases soil water potential such that plant roots fail to absorb the available water with consequent alterations in plant water relations. In response to water deficit, plants exhibit slower growth. Specific salt effects refer to injury caused by salt ions entering the plants through transpiration stream. In most of the cases, Na^+ and Cl^- ions are responsible cellular injury in plants exposed to salinity (Munns, 2005). Although EC_evalues above 4 dS m^{-1} adversely affect the growth and development in most of the crops, many salt sensitive crops are severely affected when saturation paste salinity is below 4 dS m^{-1} (Munns, 2005).

A strong majority of horticultural crops are categorized as salt sensitive. It is argued that of the total fruit species listed, about 75% are sensitive to salinity. In comparison, salt sensitive types in other crop groups range from 5-15% of the species listed (Bernstein, 1980). The two-phase inhibition of plant growth in saline soils, which involves an initial osmotic shock followed by ion injuries, differs with the crop. In annual plants, salt induced toxicity symptoms generally develop within few days while in perennial crops salt injury may become noticeable after months or even years. It has been shown that while osmotic stress equally affects both tolerant and sensitive genotypes, specific salt effects mainly hampers the growth in sensitive lines (Munns, 2005).

The perennial fruit trees differ from the annual field crops in many respects when grown in saline soils. Contrary to the annuals which generally exhibit higher salt tolerance with age, most of the fruit crops tend to become salt sensitive as they grow older. It is attributed to carry over of salts stored in roots to leaves as well as slower growth rates in older plants. Again, highly salt sensitive fruits such as citrus and stone fruits tend to accumulate Na^+ to toxic levels in soils which are essentially normal. Under certain conditions, Na^+ and Cl^- may not be the predominant ions in saline soils and the use of rootstocks that restrict the uptake of these toxic ions may render specific salt effects relatively unimportant and osmotic inhibition will thus virtually cause most of the deleterious effects in salinized fruit plants (Bernstein, 1980).

Continued development and spread of salt-affected soils (SAS) is a cause for concern and urgent efforts are required to develop and adopt salt tolerant cultivars and appropriate management practices for harnessing their productivity. In India, SAS occupy an area of about 6.73 m ha which is likely to increase in the foreseeable future. The current approaches for salinity management are mainly based on chemical amendments such as gypsum and require huge quantities of good quality water for salt leaching. Given that fresh water is

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increasingly becoming scarce and that SAS often also suffer from the problem of marginal quality groundwater, it becomes absolutely essential to place emphasis on plant-based solutions for rehabilitating the degraded saline soils (Sharma and Singh, 2015). Accordingly, identification of salt tolerant crops and cultivars and their cultivation in marginal saline lands assumes great significance (Munns, 2005). Tree plantations (e.g., fruit crops) may also significantly arrest the process of human-induced secondary salinity (Munns, 2005) with added advantages of carbon sequestration and long term improvements in soil quality (Sharma and Singh, 2015). Although most of the fruit crops are categorized as sensitive to salt stress, considerable genetic differences exist as both scion and rootstock cultivars show differential responses to salinity. While citrus rootstock Attani-1 (*Citrus rugulosa*) was tolerant to saline irrigation (25 and 50 mM NaCl), both Attanni-2 (*C. rugulosa*) and *Jatti khatti* (*C. jambhiri*) did not perform well and showed severe damage symptoms (Singh *et al.*, 2014). Among bael (*Aegle marmelos* Correa) cultivars, only NB-5 showed tolerance to soil salinity (EC_e 6.5 dS m^{-1}) while cultivars NB-9, CB-1 and CB-2 failed to withstand the salt shock (Singh *et al.*, 2015). Guava (*Psidium guajava* L.), an important fruit crop of India widely grown in tropical and sub-tropical regions, is valued for the delicious taste and high nutritional value of fruits. As guava adapts well to adverse soil conditions and has low input requirements, its commercial cultivation is an attractive proposition in marginal environments. Among the popular guava cultivars, Allahabad Safeda is reputed for high fruit yield, high vitamin C content and pleasant taste (Rathore, 2001).

Based on salt induced inhibition of shoot and root growth, guava is ranked as moderately salt tolerant with a saturation extract salinity (EC_e) tolerance threshold of about 4.7 dS m^{-1}. This threshold, however, only suggests the relative tolerance and the response to salinity may vary with climate, growing conditions and the genotype (Maas, 1993). For example, while minor reductions in plant fresh and dry weights were noted up to 8 dS m^{-1}salinity, rhizosphere salinity above 10 dS m^{-1} markedly reduced growth and about 80% decrease occurred under 11.3 dS m^{-1}salinity (Patil *et al.*, 1984).Leaf injury symptoms in guava plants first appeared as marginal chlorosis in old leaves after 2-weeks of salt treatment with 30 or 60 mM NaCl over a 10-week period. In new leaves produced after initiation of salt treatment, salt injury developed after 4 weeks of salinity exposure. While lower salinity (30 mM NaCl) did not cause any appreciable reduction in plant growth, high salt concentrations were harmful even in presence of supplemental calcium. Under saline irrigtaion (EC_{IW} 4.5 dS m^{-1}), guava cultivars Pentecoste and Paluma recorded significantly higher seed germination as compared to Surubim and IPA B-38 indicating the genotypic difference (Cavalcante *et al.*, 2005). Another finding, however, revealed that guava cultivar Paluma showed chlorosis and subsequent necrosis in leaves even with the use of marginally saline water (2 dS m^{-1}) and high salinity (8 dS m^{-1}) caused the complete cessation of growth due to accumulation of Na^+ and Cl^- ions to toxic levels. These observations point to the fact that response of guava to salinity varies with the level and duration of exposure to salinity, growing conditions and the genotype.

MATERIALS AND METHODS

This experiment was carried out during 2014-15 at ICAR-CSSRI Nain Experimental Farm (NEF), Panipat. One-year old plants of guava cultivar Allahabad Safeda, obtained from ICAR-Central Institute of Sub-tropical Horticulture were used. The NEF is located at Nain village, about 25 km away from headquarters of District Panipat, India. Geographically, it extends from 29°19'7.09'' to 29°19'10.0'' N latitude and 76°47'30.0''to 76°48'0.0'' E longitude and is located at an elevation of 230 to 231 m above the mean sea level. The farm site (~11 ha area) has barren saline lands having thick salt crust. The soil surface is mostly highly saline and is also underlain with saline water. Besides high salinity, impeded drainage and poor horizon development are the characteristic features of the farm soil (Mandal*et al.*, 2013). Subsequent to the characterization of soil, water and vegetation in the farm area, a series of technological interventions and agronomic manipulations with emphasis on plant-based solutions have been started to augment crop productivity under extreme saline conditions (ICAR-CSSRI, 2015). In this regard, an experiment was initiated in 2014 to evaluate the feasibility of commercial guava cultivation in saline soils.

Before start of the experiment, the physico-chemical properties of the experimental soil were worked out. Soil pH_2 and EC_2 were determined using a glass electrode pH meter and electrical conductivity meter (Thermo Scientific Eutech, Singapore), respectively ina suspension of soil in water (1 part soil: 2 parts water). The available N in soil wasdetermined by alkaline permanganate method(Subbiah and Asija, 1956), available P bycolorimetric method (Olsen *et al.*, 1954) and availableK by flame photometry (Jackson, 1973). The organic carbon content in soil was determined by wet oxidation method (Nelson and Sommer, 1982).After transplanting, the plants were pruned to uniform height and were irrigated with the best available water to enable better growth. Based on chemical composition (pH- 7.1, EC_{IW}- 2.8 dS m^{-1}, Na^+- 20.04 meq l^{-1} and sodium adsorption ratio- 4.86), irrigation water was categorized as marginally saline.

After one-year of growth in saline soils, plant height, stem girth and number of branches per plant were measured. Leaves from the middle of plants were sampled for mineral analyses. The collected leaves were washed in distilled water and were subsequently dried in a forced-draft oven at 60 ºC for 48 h. The dry leaves were weighed and crushed in a hammer mill. Approximately 500 mg of powdered leaf material was extracted in diacid (HNO_3 and $HClO_4$ in 3:1 ratio) at 100 ºC. Na^+ and K^+ contents were determined by using the flame photometer (Systronics, India) while Ca^{2+}concentration was measured determined through atomic absorption spectrometry (Analytik Jena, Germany).

RESULTS AND DISCUSSION

As the highest activity of feeding roots in guava is observed up to upper 25 cm soil (Rathore, 2001), soil samples were collected from 15-30 cm depth to assess the important soil properties which might influence the plant growth in saline soils. The initial physico-chemical properties of the experimental soil (Table 1) indicated moderate salinity with electrical conductivity in 1:2 soil-water suspensions (EC_2) ranging from 0.5-2 dS m^{-1}.The approximate relation between soil suspension (EC_2) and soil saturation extract (EC_e) salinities is estimated to be 1:4 implying that soil EC_e value will be about 4-fold higher against a given EC_2 value(Gupta *et al.*, 2012). Based on this relationship, the corresponding EC_e values in the experiment soil would be 2, 3.92, 5.6 and 8.0 dS m^{-1} for control, marginally saline, moderately saline and saline treatments, respectively. Soil pH values under different treatments were 7.8-8.2 indicating non-sodic nature of the experimental soil. The highest available nitrogen (315.5 kg ha^{-1}) was observed in control treatment and the lowest (284.7 kg ha^{-1}) in moderately saline plots.Available P ranged from 20.07 to 22.74 kg ha^{-1} with minor differences among different treatments. While available N increased with salinity, available P showed more or less stable values and available K decreased with the increasing salt concentration. The organic carbon content showed only marginal variation with moderately saline soils having the highest organic carbon (0.59%) content.

As saline conditions cause reduction in water uptake and result in chloride-nitrate antagonism, plants face decreased N availability. The interaction between salinity and soil phosphorus are complex and depend on factors such as type of salts and P concentration in the substrate. Salinity induced K deficiency is of common occurrence in salt-affected soils (Grattan and Grieve, 1999).

Table 1 : Physico-chemical properties of the experimental soil (15-30 cm depth)

Soil properties	Control	Marginally saline	Moderately saline	Saline
EC_2 (dS m^{-1})	0.5	0.98	1.4	2
pH_2	8.2	7.8	8.1	8.2
Available N (kg ha^{-1})	315.45	307.3	284.7	295.35
Available P (kg ha^{-1})	20.07	22.74	22.23	21.39
Available K (kg ha^{-1})	369	360.8	356.4	343
Organic carbon (%)	0.57	0.5	0.59	0.53

Data on effects of salinity on plant height stem girth, branches $plant^{-1}$ and fruits $plant^{-1}$ are given in Table 2. Salt stresssignificantly decreased survival in guava plants with over 50% of plants dying within first 3 months of planting at high salinity treatment. Plant mortality ranged from 27% in marginally saline soil to 40% in moderately saline plots. As the salinity tolerance threshold of guava is 4.7 dS m^{-1}(Maas, 1993), it is reasonable to assume that salinity above this threshold would cause reduction in shoot and root growth. In this study, control and marginally saline soils had salinities below this threshold while salt concentrations were slightly to significantly higher in moderately saline and saline plots, respectively.As most of the plant mortality occurred shortly after transplanting, without any marked leaf injury symptoms, it may be assumed that both transplanting shock and osmotic stress played greater roles than specific salt effects in reducing plant growth and survival. Salt injury became evident only in saline soils having EC_2 values of 2 dS m^{-1}. Based on response of other fruit crops such as citrus under salinity, it has been observed that osmotic stress may account for most of the adverse effects on plant growth and establishment in certain saline soils where Na^+ and Cl^- induced injury symptoms appear to be of little importance (Bernstein, 1980).

Table 2. Effect of salinity on plant growth and fruiting in guava cultivar Allahabad Safeda.

Salinity (EC_2, dS m^{-1})	Survival (%)	Plant height (cm)	Stem girth* (cm)	Branches $plant^{-1}$	Fruits $Plant^{-1}$
0.5 (Control)	80.00^{A}	98.30^{B}	2.24	7.40^{B}	9.60^{B}
0.98	73.40^{B}	108.30^{AB}	2.28	7.80^{B}	24.80^{A}
1.4	60.00^{C}	123.00^{A}	2.46	11.60^{A}	12.20^{B}
2	46.80^{D}	94.60^{B}	2.24	8.40^{B}	2.80^{C}

Means with atleast one letter common are not statistically significant using Duncan 's Multiple Range Test at 5% level of significance. *Non-significant.

Plant height increased up to 1.4 dS m^{-1} salinity and then decreased at high salinity. Plant height increased by about 10% and 25% at 0.9 dS m^{-1} and 1.4 dS m^{-1} salinities, respectively, relative to control indicating that mild salt stress stimulated growth in guava plants. High salinity caused marginal but non-significant decrease (~4%) in plant height as compared to control. Salinized plants did not show any significant difference in stem girth at different salinity levels. The highest stem girth (2.46 cm) was recorded in plants grown at 1.4 dS m^{-1} salinity. Branching in guava plants slightly increased as salinity increased from 0.5 to 0.9 dS m^{-1}. At 1.4 dS m^{-1} salinity, however, branching was considerably higher

(~57%) as compared to control. With further increase in salinity from 1.4 to 2 dS m^{-1}, branching decreased but remained comparable to control plants. In a nutshell, these data suggest that salt stress up to 1.4 dS m^{-1} was favourable to growth of guava cultivar Allahabad Safeda.Supplemental N nutrition partially ameliorates salinity induced growth reduction in guava. Guava plants irrigated with 30 mM NaCl solution showed best growth when 10 mM $Ca(NO_3)_2$ was added to the saline solution (Ali-Dinar *et al.*, 1999).In present study, available N levels were almost similar under different treatments and nitrogen nutrition does not seem to be the limiting a factor in salinized plants. Guava exhibited only about 20% decrease in growth up to 7.3 dS m^{-1}salinity (Patil *et al.*, 1984). Guava seedlings planted in a saline-sodic soil showed over 90% survival due to increase in the number of lateral roots (Sadiq, 2004).

The average number of fruits per plant in control plots was 9.6. Fruiting considerably increased (~158%) in marginally saline soils (0.9 dS m^{-1}) as compared to non-salinized plants. Further increase in salinity from 0.9 to 1.4 dS m^{-1}, however, significantly reduced the fruiting. At 1.4 dS m^{-1} salinity, fruiting was about 50% lower relative to 0.9 dS m^{-1} level but was still marginally higher (~27%) in comparison to control plants. A drastic reduction in fruiting occurred at the highest salinity as average fruits per plant decreased by about 70% relative to control.Five-year old guava plants in a saline-sodic soil (pH_s 8.8 and EC_e 4.70 dS m^{-1}) gave the maximum fruit yield (28.13 kg $plant^{-1}$) when treated with 100% GR, 40 kg FYM and 2 kg urea per plant as compared to control (4.29 kg $plant^{-1}$; Jamil *et al.*, 2011). Guava cv. Allahabad Safeda densely planted (5m x 5m) in saline soil (pH 8.18 and EC 0.95 dS m^{-1}) and drip irrigated with canal water started bearing after 3rd year of planting (Mandal *et al.*, 2007). Bael cultivar NB-5 exhibited about 66% survival and produced fruits in saline soils (ICAR-CSSRI, 2015).

Table 3 : Effect of salinity on ionic relations in leaves of guava cultivar Allahabad Safeda.

Salinity (EC_2, dS m^{-1})	Na^+ (% DW)	K^+ (% DW)	Na/K ratio	Ca^{2+} (% DW)
0.5	0.09^{BC}	0.10^{B}	0.84^{B}	0.29^{BC}
0.98	0.07^{C}	0.11^{B}	0.67^{B}	0.33^{AB}
1.4	0.09^{B}	0.13^{A}	0.72^{B}	0.37^{A}
2	0.16^{A}	0.10^{B}	1.70^{A}	0.24^{C}

Means with atleast one letter common are not statistically significant using Duncan's Multiple Range Test at 5% level of significance.

Data on ionic relations in leaves of salt stressed guava cultivar Allahabad Safeda are presented in Table 3. Salinity up to 1.4 dS m^{-1} did not have any effect on Na^+ accumulation in leaves. However, with increase in salinity from 1.4 to 2 dS m^{-1} leaves showed Na^+ concentrations close to 0.2% on dry weight basis. Salt stress also did not cause any appreciable reduction in leaf K^+ levels. Interestingly, leaf K^+ was significantly higher (~30%) at 1.4 dS m^{-1} salinity relative to control indicating preferential K^+ accumulation by roots in salt stressed plants. Owing to restricted Na^+ uptake and preferential K^+ accumulation, salt stressed guava plants maintained favourable Na^+/K^+ ratio in leaves up to 1.4 dS m^{-1} salinity. Leaf Na^+/K^+ ratio, however, was about 2-fold higher at highest salinity as compared to control. As with K^+, leaf Ca^{2+} was also found to increase up to 1.4 dS m^{-1} salinity. Leaf Ca^{2+} concentrationwas the highest (0.37% DW) at 1.4 dS m^{-1} and the lowest (0.24% DW) at 2 dS m^{-1} salinity. Leaf Na^+concentration in saline irrigated (30 and 60 mM NaCl) guava trees was in range of 0.2-0.4%. While slight reduction in growth was noted in plants having low Na^+ (0.2% DW) further increase in Na^+ concentration proved deleterious to plant growth. Adverse effects of salinity in salt stressed guava above 10 dS m^{-1} were due to successive increase in leaf Na^+ levels resulting in a higher Na^+/K^+ ratio (Patil *et al.*, 1984).Bael cultivar NB-5 maintained a favourable ionic balance in terms of low Na^+/K^+ ratio resulting in good plant performance under salinity (Singh *et al.*, 2015). Salinity-mineral nutrition interactions in horticultural crops are complex and the results vary with factors such as salt concentration, genotype and growth stage. Many horticultural species show selective uptake of K^+ over Na^+ to maintain metabolic processes, regulate ionic balance and for osmotic adjustment. In saline soils, plants suffer from reduced Ca^{2+} availability due to antagonistic ionic interactions and precipitation (Grattan and Grieve, 1999).

CONCLUSION

Based on these findings, it appears that guava cultivarAllahabad Safeda has a salinity tolerance (EC_2)threshold of about 1.5 dS m^{-1} indicating its suitability for commercial cultivation in moderately saline soils. Some of the physiological mechanisms involved in salinity alleviation in Allahabad Safeda plants include preferential root uptake of K^+ over toxic Na^+ ions as well as maintenance of sufficient Ca^{2+} levels in leaves with increasing salinity. Experiments are in progress to ascertain the effects of high saline water (~6 dS m^{-1}) on plant growth, physiology and fruiting in this cultivar so as to haveconclusive evidence regarding threshold and mechanism(s) of salt tolerance.

ACKNOWLEDGEMENT

Authors thanks Indian Council of Agricultural Research, New Delhi for providing the necessary facilities to carry out this study.

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Citation:

Singh A, Kumar A, YadavRK, Dutta Aand SharmaDK.2016.Growth and mineral nutrition in salt stressed guava (*Psidium guajava L.*) cv. Allahabad Safeda). *Journal of AgriSearch* **3** (1):21-25