# Calcium silicate application as a salt stress mitigation strategy for vegetables in the salt-affected soils of sandy plains of Kerala, India

**Abstract**

Soil salinity inhibits plant growth due to osmotic stress and reduced plant and water uptake.In the Onattukarasandy plains of Kerala, saltwater intrusion is a major problemin several panchayaths near the coastal area, . In uplands also, cultivation is not possible due to the salt stress from saltwater intrusion. One of the strategies for removing the inhibitory effect of salt stress on plant growth is the application of beneficial nutrients to the plants. Therefore,astudywascarriedouttounderstand the effect of calcium silicate application on mitigating salt stress in vegetables and using tomato as a test crop. A detailed germination study was conducted in laboratory conditions prior to pot culture experiment to find out the critical level of salinity for tomato and two salinity levels 30mM and 40mM NaCl were selected for the pot culture experiment. Foraccessingtheeffectofthevarious levels of calcium silicate on reducing salt stress in tomato,a pot culture experiment was conducted in Onattukara region (AEU 3) in completely randomized design with ten treatments replicated thrice with varying levels of $CaSiO_3$from 100kg $ha^{-1}$ to 150kg $ha^{-1}$. The treatments had a significant effect on all the biometric characteristics and yield attributes of the crop. The highest fruit weight, fruit per plant, and fruit yield were observed in treatment with soil test-based NPK recommendation and 125kg $ha^{-1}$of $CaSiO_3$applied. It was alsoobservedthat the relative water content was higher and the water saturation deficit was lower in this treatment. $CaSiO_3$application @125kg $ha^{-1}$along with soil test based recommendation of NPK can be recommended as a salt stress mitigation strategy for boosting vegetable production in the salt-affected soils of sandy plains of Kerala.

**KeyWords:**Salinity, Onattukara sandy plain, Silicon, tomato, nutrient, yield

## 1. Introduction

Saline soils contain various dissolved salts, including NaCl, $MgSO_4$, $Na_2SO_4$, KCl, $MgCl_2$, $CaSO_4$, and $Na_2CO_3$. Among soluble salts, sodium chloride (NaCl) is the dominant salt type with malignant effects on plant growth and fruit production (Al-Saady *et al.*, 2012). Kerala state has a coastal line of about 569.70 km long with nine districts adjoining the Arabian Sea, which account for 65 per cent of the total geographical area and 84 per cent of ground water resource of the state. The main salt distressed ecological units are Kuttanad, Orumundakan areas of Onattukara, Pokkali, Kaipad and Kole lands (Swarajayalakshmi et al., 2003). With detrimental effects on germination, plant vigor and crop yield, salinity is one of the most serious factors limiting the productivity of crops. The big concerns affecting 15% of the total cultivated land in the world are salinity or sodicity. 20% of total cultivated and 33% of irrigated agricultural lands worldwide are afflicted by high salinity (Shrivastava and Kumar, 2015). The impact of salinity on crop yield ~~was~~ accounted for about 30-50 per cent (Joseph and Mohanan, 2013). For all important crops, average yields in salt stressed environments are only a fraction, somewhere between 20% and 50% of record yields (Shrivastava and Kumar, 2015).

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Exogenous application of silicon is a recent eco-friendly approach to enhance the salinity stress response in plants. Under salt stress, the application of Si may lead to an increase in $K^+$ levels and a decrease in $Na^+$ levels in the cytoplasm due to $H^+$-ATPase activity in the plasma membrane and tonoplasts (Soleimannejad*et al*., 2019). Also externally supplied $Ca^{2+}$ has been shown to ameliorate the adverse effects of salinity in plant metabolism, presumably by facilitating higher $K^+/Na^+$ selectivity (Hasegawa *et al.*, 2000). Root applied Si is an important approach to decrease the undesirable effects of salt stress on plants. Adding calcium silicate in salinity stressed plants maintains membrane permeability, chlorophyll content, stomatal conductance, transpiration and net photosynthesis by diluting salts accumulated in saline environment (Murillo-Amador, 2007)

Tomatoes are considered to be moderately sensitive to salt stress, and in soils with EC greater than 2.5 $dSm^{-1}$, tomato yields are estimated to decrease about 10% per each additional EC unit (Suhandy, 2014). Tomato plants subjected to salt stress had reduced growth and development as a result of alterations in the $Na^{+}/K^{+}$ ratio. Salt water intrusion is a major problem in several panchayaths of Onattukara and it is reducing the productivity of vegetable cultivation in these areas. Therefore,thereisaneedto develop a strategy to improve the productivity of vegetables like tomato in salinity affected areas of Onattukara.

**2. Materials&Methods**

**2.1. Germination test**



To evaluate the effect of various levels of salinity on germination of tomato seeds a germination test was done in laboratory in a completely randomised design with five treatments and four replications. Seeds of the tomato variety Vellayanivijai were used in the experiment. After five minutes of surface sterilization with a 0.1% mercuric chloride solution, seeds were cleaned with distilled water that had been sterilized. For every salinity level, 25 seeds of each genotype were planted in a Petri plate and each petri dish was covered with Whatman's No. 1 filter paper and then irrigated with 5 ml of test solution. Salinity levels was created by supplementing the Hoagland solution with NaCl (Singh *et al.*, 2011). Different levels of salinity *viz.*, (10mM, 20mM, 30mM and 40mM of NaCl) was evaluated along with control (only Hoagland's solution).

To finish the seedling growth, the Petri plates were maintained in a culture environment at 20 °C with artificial light for nine hours perday. The entire treatments wasreplicated 4 times. On the fourteenth day of the experiment, measurements were made of the root and shoot's dry weight ratio, $Na^{+}/K^{+}$ ratio, germination percentage, and germination speed in days. The concentration of $Na^{+}$ and $K^{+}$ was measured with a flame photometer. Based on the results of the germination test 30mM NaCl was found to be the critical level of salinity for tomato. Therefore 30mM NaCl and one higher level of salinity (40mM NaCl) was selected for the pot culture experiment.

**2.1. Evaluating the effect of calcium silicate to mitigate salt stresss in vegetables**

To study the effect of different levels of calcium silicate application on salt stressed tomato plants, apot cultureexperimentwasconductedinAEU3 using completely randomized design with ten treatmentsandthree replications.The pot culture experiment was conducted at Onattukara Regional AgriculturalResearch Station, Kayamkulam, Alappuzha, Kerala. The field was located in theAEU-3(OnattukaraSandyPlain).Soiltypewassandyloamsoilandfieldexperimentwasconducted from January to April2024. The soil of the experimental plot comes under the taxonomic family ofLoamy skeletal kaoliniticisohyperthermicUstic*Quartzipsamments*.

Treatments ($T_1$ to $T_5$) were tested at two levels of salt stress i.e., 30mM and 40 mM NaCl. Salinity levels was fixed based on the results of germination test. Salt stress were induced by irrigating with NaCl solutions corresponding to the required salinity levels.Salt stress was induced at 30 DAT. 1/3 $^{rd}$ dose of each level of salinity was applied on first day (30DAT), 2/3 $^{rd}$ dose was applied on $4^{th}$ day and full dose were applied on $7^{th}$ day.

Recommended dose of fertilizers and organic manures for tomato as per package of practices (KAU, 2016): FYM @ 20 t $ha^{-1}$ + 75:40:25 kg N: $P_2O_5$:$K_2O$ $ha^{-1}$ was given in $T_1$. From the ~~intial~~initial analysis of the soil samples the soil test based recommendation ~~arrived~~ for the tomato plants was 117:11:136 of N:$P_2O_5$:$K_2O$kg $ha^{-1}$ as per NPK rating and recommendation suggested by the Kerala Agricultural University (2016). Lime was appliedatarateof250kgha$^{-1}$. Alongwithsoiltestbased recommendation of primary nutrients ,Calcium silicate was also applied as basal dose with three levels,100 kg $ha^{-1}$, 125kg $ha^{-1}$ and 150 kg $ha^{-1}$ . Different biometric observations such as plant height at harvest, number of branches at harvest, fruit set

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percentage and yield attributes,andfruit quality parameters were recorded. Water relations such as relative water content and water saturation deficit were also noted.

### 3. ResultsandDiscussion

### 3.1. Germination test

The data regarding effect of different levels of salinity on germination percentage, no: of days for germination, root shoot dry weight ratioand $Na^+$/ $K^+$ ratio of shoot and root of tomato seedlings are presented in Table 1 and 2.When salt concentration increased, germination of tomato seed was reduced and the time needed to complete germination lengthened, root/shoot dry weight ratio was higher and $Na^+$ content increased but $K^+$ content decreased.

The germination percentage of tomato seeds declined drastically from 96.52 % (control) to 30.87 % (at 40 mM NaCl ). The effect of external salinity on seed germination may be partially osmotic or ion toxicity, which can alter physiological processes such as enzyme activities (Croser*et al.*, 2001; Essa and Al-Ani, 2001). It is inferred that the speed of germination was reduced i.e. it took more days to complete the germination under salinity. The treatment $T_5$ ( Hoagland solution containing 40 mM NaCl ) recorded the highest number of days for germination (12.15 days). The salinity notablyaffects germination in many species but also lengthens the time needed to complete germination (Amir *et al.*, 2011).

In spite of the negative effects of salt on roots, the root growth in tomato appears to be less affected whereas, shoot was affected drastically, so that, the dry weight ratio was higher in plant grown under salt stress than in control environment. The highest root/shoot dry weight ratio was observed at higher salinity, $T_5$ (Hoagland solution containing 40 mM NaCl). It may occur due to the mechanism of dry matter partitioning in stress conditions. Seedling send more assimilates to roots to improve uptake ability and so the seedling above ground growth may be declined. Theseresultsareintheline withthefindings of Hamed *et al.* 2011.

$Na^+$/ $K^+$ ratio of both shoot and root of tomato seedlings increased with increasing salinity. It might be due to antagonistic effects of $Na^+$ and $Ca^{2+}$ on $K^+$ absorption and abnormal $Na^+$/$K^+$ or $Ca^{2+}$/$K^+$ratio . Increased concentrations of $Na^+$ block channel protein used for the uptake of $K^+$, and in this way reduce the uptake of $K^+$ (Qi and Spadling, 2004).

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### 3.2. Evaluating the effect of calcium silicate to mitigate salt stress in vegetables

#### 3.2.1. Biometric observations

Biometricobservationssuchasplantheightat harvest, number of branches at harvest and fruit set percentage showed significant difference with the treatments applied (Table 3 & 4). Plant height was the highest in treatment $T_5$ (Soil test based POP + $CaSiO_3$ @ 150 kg $ha^{-1}$ @ 30 mM salt stress) at harvest.This may be attributed to the fact that silicon helps in increasing the erectness of leaves therebyenhancing photosynthetic capacity which results in higher plant height. Similar findings were reported by Fallah , 2012 in rice under hydroponic culture.Increase in plant height withSi application might be due to its hydrophilic nature, which helps plants to tolerate salt toxicity by improving the water economy of the plant.

The number of branchesat harvest was the highest in $T_5$( Soil test based POP + $CaSiO_3$ @ 150 kg $ha^{-1}$ @ 30 mM salt stress). Silicon addition helped plant growth, which might be due to the increased synthesis of photosynthates by the silicon addition and it was exerted in the increased number of branches. The increase in number of branches is due to higher nutrient use efficiency, physiological efficiency and photosynthetic rates (Ma *et al.,* 2001).

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Application of treatment $T_4$ ( Soil test based POP + $CaSiO_3$ @ 125 kg $ha^{-1}$ @ 30 mM salt stress) registered the highest value of fruit setpercentage of 80.85%. The fruit set percentage may behigh due to the fact that application of silicon on the plants led to an improvement in leaf design with more erect leaves that intercept high solar light, boosting the photosynthetic efficiency and chlorophyll content. Application of silixol granules @ 10 mg $kg^{-1}$ recorded the highest fruit setting percentage of tomato in coastal saline soil ( Elayaraja, 2020). These findings are also in conformity with those of Marodin*et al.,* 2014.

**3.2.2. Yield attributes**

The results of the study on the effect of on yield and yield attributes of salt stressed tomato showed that different treatments had a substantial impact on the number of fruits per plant, fruit weight, and yield per plant (Table 5). The maximum number of fruits per plant, fruit weight and yield per plant were recorded in $T_4$ ( Soil test based POP + $CaSiO_3$ @ 125 kg $ha^{-1}$ @ 30 mM salt stress). Increase in yield attributes of tomato due to silicon application might be due to higher photosynthetic activity of plant, more formation of carbohydrates and more uptakes of other nutrients. Similar results were also noticed by Gholami and Falah, 2013.

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**3.2.3. Fruit quality parameters**

The highest TSS and ascorbic acid content were noticed in $T_4$ ( Soil test based POP + $CaSiO_3$ @ 125 kg $ha^{-1}$ @ 30 mM salt stress) (Table 6) whereas highest lycopene content was noticed in both $T_4$ ( Soil test based POP + $CaSiO_3$ @ 125 kg $ha^{-1}$ @ 30 mM salt stress) and $T_5$ ( Soil test based POP + $CaSiO_3$ @ 150 kg $ha^{-1}$ @ 30 mM salt stress). Fruit quality might have influenced by the calcium silicate application probably due to a suppression of respiration and a reduction in ethylene evolution. These findings were in accordance with Savvas, 2009 who reported that application of silicon under salinity stress conditions enhanced the fruit firmness, total soluble solids, β-carotene, lycopene and vitamin C in the tomato fruits. Stamatakis *et al.*, 2003 studied the effect of silicon and salinity on fruit yield and quality of tomato and reported that Total Soluble Solids (TSS), β-carotene, vitamin-C and lycopene contents of fruits were significantly increased by silicon.

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**3.2.4. Water relations**

The highest Relative water content was observed in $T_4$ ( Soil test based POP + $CaSiO_3$ @ 125 kg $ha^{-1}$ @ 30 mM salt stress) whereas $T_6$ (RDF and organic manure as per POP @ 40 mM salt stress ) recorded the highest value for water saturation deficit (Fig. 1.). The higher water status in salt-stressed plants in the presence of Si may be due to the reduction in excessive loss of water by transpiration. It was suggested that Si was deposited in the epidermal cells of aerial parts of plants, leaves and stems that decreased the water loss through the cuticle and the higher water content maintained by Si diluted the salts in plant body and consequently reduced deleterious effects of salinity on plant growth (Romero *et al.,* 2006). Si application maintains higher water status, photosynthetic activity and better plant defense system and membrane permeability/stability ( Ali*et al.*, 2011).

## CONCLUSION

The findings of this pot culture study suggest that the application of Calcium silicate @125 kg ha$^{-1}$ ameliorated the ill effects of salinity on crop growth and yield and recorded the highest yield of 1.99kg/plant. The addition of calcium silicate at the rate of 125 kg ha$^{-1}$was found to be best for biometric observations, fruit quality parameters, yield attributes and water relations. The lowest water saturation deficitwas also recorded from the treatment applied withcalcium silicate at the rate of 125 kg ha$^{-1}$. The use of calcium silicate may contribute to reduce the negative effects of salinity and can be utilized as an effective tool for mitigating salt stress in vegetables.

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Table 1. Effect ofdifferent levels of salinity on Germination percentage, no: of days forgermination and root shoot dry weight ratio.

| **Treatments** | **Germinationpercentage (%)** | **Days for germination** | **Root shoot dry weight ratio** |
|---|---|---|---|
| $T_1$ – Absolute control (Hoagland solution containing 0 mM NaCl) | 96.52 | 3.70 | 0.433 |
| $T_2$ - Hoagland solution containing 10 mM NaCl | 90.15 | 4.10 | 0.440 |
| $T_3$ - Hoagland solution containing 20 mM NaCl | 78.82 | 5.50 | 0.468 |
| $T_4$ - Hoagland solution containing 30 mM NaCl | 59.97 | 9.05 | 0.552 |
| $T_5$ - Hoagland solution containing 40 mM NaCl | 30.87 | 12.15 | 0.611 |
| SE(m) | 0.624 | 0.158 | 0.002 |
| CD (5%) | 1.882 | 0.478 | 0.005 |

Table 2. Effect ofdifferent levels of salinity on $Na^+$/ $K^+$ ratio of shoot and root of tomato seedlings.

| **Treatments** | **$Na^+$/ $K^+$ ratio of shoot** | **$Na^+$/ $K^+$ ratio of root** |
|---|---|---|
| $T_1$ – Absolute control (Hoagland solution containing 0 mM NaCl) | 2.230 | 1.910 |
| $T_2$ - Hoagland solution containing 10 mM NaCl | 2.460 | 2.087 |
| $T_3$ - Hoagland solution containing 20 mM NaCl | 2.885 | 2.197 |
| $T_4$ - Hoagland solution containing 30 mM NaCl | 3.638 | 2.900 |
| $T_5$ - Hoagland solution containing 40 mM NaCl | 4.210 | 3.365 |
| SE(m) | 0.030 | 0.027 |

| | | |
|---|---|---|
| CD (5%) | 0.090 | 0.082 |

Table 3. Effect of Calcium silicate on plant height(cm) and number of branches at harvest

| **Treatments** | **Plant height at harvest (cm)** | **No: of branches at harvest** |
|---|---|---|
| $T_1$ - Recommended dose of fertilizers and organic manures as per POP ( 30 mM salt stress) | 35.05 | 3.20 |
| $T_2$ - Soil test based POP ( 30 mM salt stress) | 35.15 | 3.51 |
| $T_3$ - Soil test based POP + Calcium silicate @100 kg $ha^{-1}$ ( 30 mM salt stress) | 42.55 | 4.23 |
| $T_4$ - Soil test based POP + Calcium silicate @125 kg $ha^{-1}$ ( 30 mM salt stress) | 46.15 | 4.45 |
| $T_5$ - Soil test based POP + Calcium silicate @150 kg $ha^{-1}$ ( 30 mM salt stress) | 47.20 | 5.05 |
| $T_6$ - Recommended dose of fertilizers and organic manures as per POP ( 40 mM salt stress) | 30.75 | 3.05 |
| $T_7$ - Soil test based POP ( 40 mM salt stress) | 32.30 | 3.30 |
| $T_8$ - Soil test based POP + Calcium silicate @100 kg $ha^{-1}$ ( 40 mM salt stress) | 40.30 | 4.10 |
| $T_9$ - Soil test based POP + Calcium silicate @125 kg $ha^{-1}$ ( 40 mM salt stress) | 44.10 | 4.33 |
| $T_{10}$- Soil test based POP + Calcium silicate @150 kg $ha^{-1}$ ( 40 mM salt stress) | 44.65 | 4.95 |
| SE(m) | 1.684 | 0.276 |
| CD (0.05) | 5.306 | 0.870 |



Table 4. Effect of Calcium silicate on fruit set percentage (%)

| Treatments | Fruit set (%) |
|---|---|
| $T_1$ - Recommended dose of fertilizers and organic manures as per POP ( 30 mM salt stress) | 55.50 |
| $T_2$ - Soil test based POP ( 30 mM salt stress) | 59.50 |
| $T_3$ - Soil test based POP + Calcium silicate @100 kg ha$^{-1}$ ( 30 mM salt stress) | 70.00 |
| $T_4$ - Soil test based POP + Calcium silicate @125 kg ha$^{-1}$ ( 30 mM salt stress) | 73.75 |
| $T_5$ - Soil test based POP + Calcium silicate @150 kg ha$^{-1}$ ( 30 mM salt stress) | 72.25 |
| $T_6$ - Recommended dose of fertilizers and organic manures as per POP ( 40 mM salt stress) | 54.65 |
| $T_7$ - Soil test based POP ( 40 mM salt stress) | 58.10 |
| $T_8$ - Soil test based POP + Calcium silicate @100 kg ha$^{-1}$ ( 40 mM salt stress) | 67.60 |
| $T_9$ - Soil test based POP + Calcium silicate @125 kg ha$^{-1}$ ( 40 mM salt stress) | 69.25 |
| $T_{10}$- Soil test based POP + Calcium silicate @150 kg ha$^{-1}$ ( 40 mM salt stress) | 69.25 |
| SE(m) | 1.933 |
| CD (0.05) | 6.091 |



Table 5. Effect of Calcium silicate on yield attributes of tomato plant

| Treatments | Fruits per plant | Fruit weight(g) | Yield per plant (kg) |
|---|---|---|---|
| $T_1$ - Recommended dose of fertilizers and organic manures as per POP ( 30 mM salt stress) | 40.10 | 21.05 | 0.61 |
| $T_2$ - Soil test based POP ( 30 mM salt stress) | 42.90 | 25.15 | 0.79 |
| $T_3$ - Soil test based POP + Calcium silicate @100 kg ha$^{-1}$ ( 30 mM salt stress) | 58.75 | 31.25 | 1.76 |
| $T_4$ - Soil test based POP + Calcium silicate @125 kg ha$^{-1}$ ( 30 mM salt stress) | 67.65 | 35.90 | 1.99 |
| $T_5$ - Soil test based POP + Calcium silicate @150 kg ha$^{-1}$ ( 30 mM salt stress) | 59.00 | 35.35 | 1.79 |
| $T_6$ - Recommended dose of fertilizers and organic manures as per POP ( 40 mM salt stress) | 38.90 | 19.50 | 0.42 |
| $T_7$ - Soil test based POP ( 40 mM salt stress) | 41.65 | 23.00 | 0.60 |
| $T_8$ - Soil test based POP + Calcium silicate @100 kg ha$^{-1}$ ( 40 mM salt stress) | 53.35 | 30.00 | 1.01 |
| $T_9$ - Soil test based POP + Calcium silicate @125 kg ha$^{-1}$ ( 40 mM salt stress) | 58.05 | 34.15 | 1.83 |
| $T_{10}$- Soil test based POP + Calcium silicate @150 kg ha$^{-1}$ ( 40 mM salt stress) | 53.45 | 31.30 | 1.22 |
| SE(m) | 1.147 | 1.003 | 0.069 |
| CD (0.05) | 3.614 | 3.161 | 0.216 |

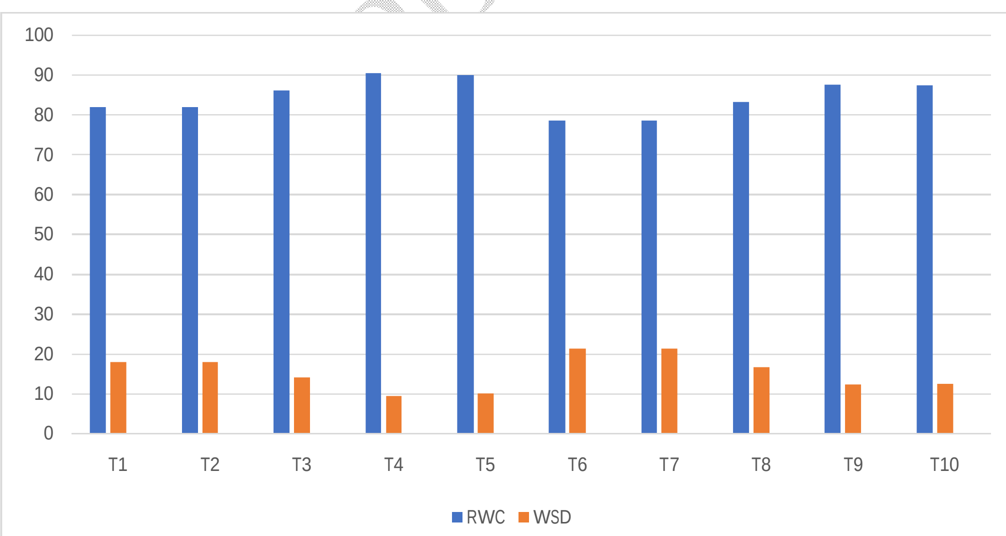
Table 6. Effect of Calcium silicate on fruit quality parameters

| Treatments | TSS($^0$B) | Ascorbic acid (mg 100g$^{-1}$) | Lycopene (µg cg$^{-1}$) |
|---|---|---|---|

| | | | |
|---|---|---|---|
| $T_1$- Recommended dose of fertilizers and organic manures as per POP ( 30 mM salt stress) | 2.90 | 14.69 | 0.10 |
| $T_2$ - Soil test based POP ( 30 mM salt stress) | 3.08 | 14.86 | 0.10 |
| $T_3$ - Soil test based POP + Calcium silicate @100 kg $ha^{-1}$ ( 30 mM salt stress) | 3.38 | 19.65 | 0.11 |
| $T_4$ - Soil test based POP + Calcium silicate @125 kg $ha^{-1}$ ( 30 mM salt stress) | 4.06 | 23.27 | 0.12 |
| $T_5$ - Soil test based POP + Calcium silicate @150 kg $ha^{-1}$ ( 30 mM salt stress) | 4.03 | 22.93 | 0.12 |
| $T_6$ - Recommended dose of fertilizers and organic manures as per POP ( 40 mM salt stress) | 2.72 | 13.04 | 0.09 |
| $T_7$ - Soil test based POP ( 40 mM salt stress) | 2.88 | 13.16 | 0.10 |
| $T_8$ - Soil test based POP + Calcium silicate @100 kg $ha^{-1}$ ( 40 mM salt stress) | 3.09 | 17.96 | 0.10 |
| $T_9$ - Soil test based POP + Calcium silicate @125 kg $ha^{-1}$ ( 40 mM salt stress) | 3.89 | 22.20 | 0.11 |
| $T_{10}$- Soil test based POP + Calcium silicate @150 kg $ha^{-1}$ ( 40 mM salt stress) | 3.86 | 21.91 | 0.11 |
| SE(m) | 0.04 | 0.285 | 0.002 |
| CD (0.05) | 0.126 | 0.898 | 0.007 |



Fig. 1.Effect of Calcium silicate on relative water content(RWC) and water saturation deficit(WSD)



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