# STRATEGIES FOR IMPROVING RESILIENCE TO ABIOTIC STRESSES IN SUMMER GROUNDNUT


## Abstract

Significant improvement in growth, yield, physiological traits, water use efficiency and economic aspects of summer groundnut cultivation on medium black calcareous clayey soil was observed due to appropriate irrigation, residue mulching and the foliar application of stress-reducing chemicals. A study was conducted during the summer of 2022 and 2023 at the Instructional farm of Junagadh Agricultural University, India, to assess various irrigation techniques (drip and surface irrigation), residue mulching and stress-mitigating chemicals (salicylic acid, potassium nitrate, and kaolin) in combating environmental stress on summer groundnut. The results showed that using drip irrigation at 0.8 PEF resulted in improved growth, yield, physiological traits, water use efficiency and economics of summer groundnut. Residue mulching was also discovered to be effective in decreasing soil water loss. The mulch rate of 5 t $ha^{-1}$ was determined to be the most effective for growth, yield, physiological traits, water use efficiency and economics. Different chemical compounds for reducing stress also had a significant impact on these factors. During this study, combining drip irrigation at 0.8 PEF, mulching with 5 t $ha^{-1}$ of residue and applying salicylic acid (foliar) at 100 ppm during 45 and 60 days after sowing enhanced the growth, yield and physiological traits, water use efficiency and economics of summer groundnut in areas with limited irrigation.



***Key words*:** Abiotic stress, Irrigation, Residue mulching, Stress mitigation chemicals, Summer


## Introduction

Abiotic stresses exert a pivotal influence on the productivity, sustainability and resilience of Indian agriculture, with diverse agro-climatic zones making the country susceptible to a range of challenges. From droughts and erratic rainfall to extreme temperatures and soil-related issues, these stresses significantly impact crop yields, threatening food security. Climate change-induced stresses can result in a drastic reduction of up to 70% crop yield, while edaphic stresses like nutrient deficiencies and salinity further compound challenges in crop production.

Peanut is a significant oilseed crop that contains 44-56% oil and 22-30% protein when measured on a dry seed basis. Groundnut plants have developed different physiological characteristics to endure harsh conditions in order to cope with the adverse effects of abiotic stress. Research findings show that using different irrigation techniques, residue mulching and stress mitigation chemicals can greatly improve crop growth, yield, physiological traits and water use efficiency in summer groundnut while managing abiotic stress.

Studies show that drip irrigation significantly enhances pod and haulm yield, water and fertilizer savings, and net returns compared to traditional surface irrigation methods (Vaghasia *et al*. 2023). Mulching, particularly with crop residue, positively impacts yield attributes and economic returns by conserving soil moisture and improving nutrient uptake (Maurya *et al*. 2024). Stress mitigating chemicals such as Salicylic acid, potassium nitrate and kaoline enhance physiological parameters like relative water content, photosynthetic rate, and membrane stability index under stress conditions, providing effective solutions for managing water stress in groundnut (Menpadi, 2017).

This study investigates the management of abiotic stress in summer groundnut cultivation. It analyses stressors, including temperature extremes and moisture deficit. The research aims to understand the impacts of these stressors on growth, yield, physiological traits, water use efficiency and economics. It also explores resilient strategies, such as irrigation management techniques combined with mulching practices and foliar application of stress mitigation chemicals. The findings could contribute to sustainable agricultural practices for enhancing productivity and resilience profitability under abiotic stress conditions.

## METHODOLOGY

### Site characterization

Field trials were conducted in medium black clay soil under irrigated conditions at the Instructional farm of the Junagadh Agricultural University, in summer 2022 and 2023. South Saurashtra Agro-climatic region of Gujarat state has a tropical wet and dry climate, with three distinct seasons observed, a mild winter sets in the month of November and continues till the month of February. December and January are the coldest month of winter. Summer season commences during the second fortnight of February and ends by middle of June and a monsoon from July to October. Junagadh faces adverse climatic conditions in the summer months with the temperature ranging from 28 ºC to 38 ºC. April and May are the hottest months of summer. In the winter months, the temperature ranges from 10 ºC to 25 ºC. Various factors such as its close proximity to the sea influence the weather of Junagadh. The latent winds from the sea affect the climatic conditions in the region Chinchorkar *et al*. (2022).

The soil is classified as Vertic Ustochrept, medium black, clayey, shallow (15-20 cm depth) and highly calcareous in nature (pH 7.9). The soil contains moderate available nitrogen (257 kg $ha^{-1}$), medium available phosphorus (37.68 kg $ha^{-1}$) and high in available potassium (276.8 kg $ha^{-1}$), EC 0.41 dS $m^{-1}$, medium organic carbon (0.58%) with soil pH of 8.1. The bulk density of the experimental soil were 1.33 g $cm^{-3}$. Field capacity and permanent wilting point were around 27.63 to 28.37% and 13.39 to 14.21% gravimetric water contents, respectively.

### Crop management

The variety of summer groundnut used in this study was Gujarat Junagadh Groundnut-31. The crop was sown on 15th and 10th February in 2022 and 2023, respectively. Seed rate and spacing of growing the crop were 120 kg $ha^{-1}$ and 30 cm * 10 cm.

Gap filling operation was done during 12-15 DAS in each row to maintain proper plant to plant spacing of 10 cm. The total amount of fertilizers were applied at the time of sowing. For effective weed management, pre-emergence application of Pendimethalin at 1.0 kg *a.i*. $ha^{-1}$ was used. Two common irrigation was applied for uniform germination. After proper germination drip installation and residue mulching treatment was applied in respected plot. Threshing of the crop was done on 19th June, 2022 and 16th June, 2023. Respectively.

### Treatment

The experiment was laid out in a split split plot design having three replications. Main plot comprised of three of irrigation methods and scheduling on the basis of IW/CPE ratio and PEF *viz*. surface irrigation at 1.0 IW/ CPE and drip irrigation at 0.6 and 0.8 PEF, different mulching i.e. residue mulch 5 t ha$^{-1}$ and no mulch were taken at sub-plots. While different stress mitigation chemicals foliar application at 45 and 60 DAS *viz*. Control, Salicylic acid at spray @ 100 ppm, Potassium nitrate spray @ 2% and Kaolin spray @ 6% were taken at sub sub-plots treatments. Thus, the experiment was comprised of total 24 treatment combinations.

**Table 1. Evaluation of hydraulic performance of drip irrigation system**

| Variation | First lateral | Middle lateral | Last lateral | Average |
|---|---|---|---|---|
| Maximum Discharge (lph) | 3.48 | 3.52 | 3.46 | 3.49 |
| Minimum Discharge (lph) | 2.98 | 3.17 | 3.00 | 3.05 |
| Average of Discharge (lph) | 3.23 | 3.35 | 3.23 | 3.27 |
| Average of 1/4 the lowest emitter discharge (lph) | 3.14 | 3.22 | 3.14 | 3.17 |
| Standard deviation (SD) | 0.14 | 0.10 | 0.13 | 0.12 |
| Coefficient of variation ($Q_{var}$) | 0.04 | 0.03 | 0.04 | 0.04 |
| Uniformity coefficient (%) | 95.67 | 97.01 | 95.98 | 96.22 |
| Distribution Uniformity (%) | 97.21 | 96.26 | 97.21 | 96.90 |
| Emission Uniformity (%) | 98.04 | 94.67 | 98.04 | 96.92 |

Performance of drip irrigation was evaluated based on the uniformity coefficient, distribution uniformity and emission uniformity by measuring the discharge from first, middle and end laterals for 5 minutes and then converted into the lph. The hydraulic performance of drip system is as summarized in table 1. The system was made to run at fixed pressure (1 kg cm$^{-2}$) throughout the period of experiment. The maximum discharge observed as 3.52, 3.48 and 3.46 lph at starting point of the lateral in middle, first and last lateral respectively. Minimum discharge was occurred at first lateral then followed by last and middle lateral respectively. The average discharge of first, middle and last lateral was 3.33, 3.35 and 3.31 respectively, with overall average discharge of system was 3.33 lph which was 83.33 % of manufacturer discharge (4 lph). As such this is considered as a good discharge.

A common irrigation was applied at sowing and 7 DAS to ensure proper germination as well as establishment of the crop irrespective of cumulative pan evaporation readings. Afterward, irrigations were given as per irrigation treatment. This is a climatological approach of scheduling irrigation. In this approach a known amount of irrigation water (IW) is applied when cumulative pan evaporation CPE reaches a predetermined level. Pan evaporation denoted the water loss because of evaporation from an open pan evaporimeter. The total amount of irrigation water (IW) was applied in each irrigation was 50 mm per irrigation during both the years. Therefore, the cumulative pan evaporation value was 50 mm at 1.0 IW/CPE ratio. Irrigation frequency was varied at same level of IW/CPE ratio due to variation in rainfall in crop duration. While in drip irrigation alternate day irrigation was given at different pan evaporation fraction. Sowing of seeds in plot was done in 9 rows having spacing of 30 cm row-row and 10 cm plant-plant. Crop residue at 5000 kg ha$^{-1}$ was applied under mulching treatment after both common irrigation and drip installation, while, under no-mulch no crop residue was applied. Mulch was uniformly spread in between the rows of crop. Application of different stress mitigation chemicals was given at 45 DAS and 60 DAS via foliar spray.

**Growth parameters**

Plant height, number of branches and dry matter production at harvest by selecting random 5 plant sample per plot and mean data were analysis.

**Yield**

Various yield attributes like number and weight of pod per plant as well as yield like pod, haulm and kernel yield were recorded per plot.

**Physiological traits**

The SPAD meter value was measured at 60, 90 DAS and at harvest by using the chlorophyll meter (Minolta SPAD-502) by taking observations from 4-5 upper leaves of five tagged plants and averaged for best result. The values were recorded as SPAD values. Relative water content (RWC) was assessed according to Barrs and Weatherly (1962) method with the following formula,

$$\textbf{Relative water content}\ (\%) = \frac{Fresh\ weight\ (g) - Dry\ weight\ (g)}{Turgid\ weight\ (g) - Dry\ weight\ (g)} \times 100$$

Membrane stability index (MSI) was calculated by taking the electrical conductivity of leaf leachates in double distilled water at 40 and 100°C by following the method of Sairam (1994).

$$\textbf{Membrane stability index (MSI)} = \left(1 - \frac{C1}{C2}\right) x\ 100$$

Mature leaf was cut into small pieces and then taken (0.5 g) in test tubes having 10 ml. of double distilled water in two sets. One set was kept at 40ºC for 30 min and another set at 100ºC in boiling water bath for 15 min and their respective electric conductivity's $C_1$ and $C_2$ were measured by conductivity meter.

**Water Use Efficiency (kg/ha mm)**

The response of pod yield per unit of irrigation water applied at varying levels of irrigation was worked out by dividing per hectare pod yield of groundnut crop obtained under various treatments with the total quantity of irrigation water applied (mm) which was worked out by the following formula.

$$\textbf{WUE (Kg ha}^{-1}\textbf{mm}^{-1}\textbf{)} = \frac{\text{Pod yield (Kg ha}^{-1}\text{)}}{\text{Water applied (mm)}}$$

**Data analysis**

Standard analysis of variance was used to do the statistical analysis of the data (Cochran and Cox (1957), Gomez and Gomez, 1984). The F-test was used to assess the treatment effects' significance. Using the least significant difference (LSD) at the 5% probability level, the significance of the difference between the means of the different treatments was examined.

**Economic analysis**

The yield and cost-effectiveness of irrigation, residue mulching and stress mitigation chemicals were evaluated to determine whether to add more groundnut production. Utilizing crop yield and produce market price, net realization return and benefit cost ratio were computed to compare the economics.

## RESULTS AND DISCUSSION

The analysis of variance (ANOVA) for different parameters tested in this experiment exhibited that the main effects of various irrigation, residue mulching and stress mitigation chemicals were significant for almost all the parameters like growth, yield, physiological traits, water use efficiency and economics *etc*. during both the years of experiment (Table 2, 3 & 4). The interaction effects between irrigation with residue mulch (I*M), Irrigation with stress mitigation chemicals (I*S), residue mulching combined with stress mitigation chemicals (M*S) and irrigation, residue mulching and stress mitigation chemicals (I*M*S) were significant during both the years of study as well as pooled results (Fig 1&2).

Drip irrigation at 0.8 PEF recorded significantly highest growth parameters, yield attribute and yield compared to surface irrigation at 1.0 IW/CPE. This may be due to irrigation at 0.8 PEF proved adequate to grow the plant under moisture stress free condition that helped in better cell division and cell expansion of plant and finally resulted in better plant. When the plant is grown under constantly replenished appreciable soil moisture, it tends to grow at its genetic potential while extending out plant height, number of branches and dry matter production for active photosynthesis. The results completely collaborated with the results reported by Suresh *et al*. (2013), Ranjitha *et al*. (2018) and Chandini *et al*. (2022). Higher number of pods per plant with precise irrigation by drip irrigation at 0.8 PFE ($I_3$) could be due to the occurrence of sufficient available soil moisture condition in the root zone during the crop growth period and higher uptake of nutrients under this treatment might have produced and converted more photosynthates into numerous metabolites needed for such yield attributes. Sufficient moisture at required frequency with required quantity at reproductive stage improve the pegging and also make favourable soil environment for pod development, thereby increasing number of pods per plant. While in surface irrigation treatment loss of water is more and plant experience the abiotic stress at reproductive stage. So, decrease pegging as well as number of pods per plant. These results are in conformity with the findings of those reported by Mathukia *et al*. (2019), Maurya *et al*. (2019), Eman *et al.* (2022) and Harini *et al*. (2022). In the present study all growth and yield attributes were positively and highly correlated with the pod and haulm yield of groundnut. These observations are in conformity with those reported by Kamble *et al*. (2017), Londhe *et al*. (2017), Jain *et al.* (2018), Swetha and Bhunia (2019), Chandrasekaran *et al*. (2020), Kaur *et al*. (2020), Ramanjaneyulu *et al*. (2021), Solanke *et al*. (2021), Kumar *et al*. (2022), Metin *et al*. (2023) and Vaghasiya *et al*. (2023).

**Table 2. Effect of resilient strategies on growth parameters, yield attribute and yield of summer groundnut**

| Treatment | Plant height (cm) | Number of branches | Dry matter production (g plant$^{-1}$) | Number of pod per plant | Pod yield (q ha$^{-1}$) | Haulm yield (q ha$^{-1}$) |
|---|---|---|---|---|---|---|
| **Irrigation (I)** | | | | | | |
| **$I_1$** | 20.07 | 4.13 | 25.44 | 10.13 | 31.00 | 46.30 |
| **$I_2$** | 23.33 | 4.65 | 26.66 | 10.68 | 32.64 | 48.39 |
| **$I_3$** | 26.92 | 5.31 | 32.40 | 13.40 | 40.73 | 59.74 |
| **SEM** | 0.38 | 0.06 | 0.45 | 0.17 | 0.51 | 0.90 |
| **CD 5%** | 1.25 | 0.20 | 1.47 | 0.56 | 1.67 | 2.94 |
| **CV %** | 11.32 | 9.14 | 11.10 | 10.51 | 10.18 | 12.11 |
| **Residue Mulch (M)** | | | | | | |
| **$M_0$** | 22.39 | 4.46 | 26.72 | 10.78 | 32.95 | 48.83 |
| **$M_1$** | 24.49 | 4.94 | 29.62 | 12.02 | 36.63 | 54.12 |
| **SEM** | 0.26 | 0.05 | 0.32 | 0.13 | 0.38 | 0.60 |
| **CD 5%** | 0.79 | 0.14 | 0.99 | 0.40 | 1.17 | 1.86 |
| **CV %** | 9.25 | 8.24 | 9.66 | 9.57 | 9.25 | 9.96 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Stress Mitigation chemicals (S)** | | | | | | | |
| **$S_0$** | | 21.44 | 4.31 | 26.17 | 10.48 | 32.07 | 47.68 |
| **$S_1$** | | 24.83 | 5.04 | 29.56 | 12.05 | 36.71 | 54.13 |
| **$S_2$** | | 23.07 | 4.78 | 28.72 | 11.62 | 35.44 | 52.46 |
| **$S_3$** | | 24.42 | 4.66 | 28.23 | 11.45 | 34.95 | 51.64 |
| **SEM** | | 0.32 | 0.06 | 0.37 | 0.16 | 0.46 | 0.68 |
| **CD 5%** | | 0.90 | 0.17 | 1.04 | 0.44 | 1.29 | 1.93 |
| **CV %** | | 8.20 | 7.49 | 7.88 | 8.17 | 7.90 | 7.97 |
| **I X M** | **SEM** | 0.44 | 0.08 | 0.56 | 0.22 | 0.66 | 1.05 |
| | **CD 5%** | 1.36 | 0.24 | 1.71 | 0.69 | 2.02 | 3.22 |
| **I X S** | **SEM** | 0.56 | 0.10 | 0.64 | 0.27 | 0.79 | 1.18 |
| | **CD 5%** | 1.56 | 0.29 | 1.81 | 0.76 | 2.24 | 3.34 |
| **M X S** | **SEM** | 0.45 | 0.08 | 0.52 | 0.22 | 0.65 | 0.97 |
| | **CD 5%** | 1.28 | 0.23 | 1.47 | 0.62 | 1.83 | 2.73 |
| **I X M X S** | **SEM** | 0.78 | 0.14 | 0.91 | 0.38 | 1.12 | 1.68 |
| | **CD 5%** | 2.21 | 0.40 | 2.55 | 1.07 | 3.16 | 4.72 |
| **Y** | **SEM** | 0.31 | 0.05 | 0.37 | 0.14 | 0.42 | 0.73 |
| | **CD 5%** | NS | NS | NS | NS | NS | NS |

While residue mulch @ 5 $tha^{-1}$ recorded significant effect on summer groundnut. Probably due to better soil moisture conservation and temperature regulation provided by the mulch, this trend was sustained at harvest, where mulched plants logged greater growth parameters. This attests to a long-term positive effect of mulch on plant vigour and general resilience to such abiotic stresses as moisture deficit and extremes in temperature. This might be because of more moisture availability to the plants throughout its growth period and thus increase in physiological and metabolic processes within plants, providing a growth environment that improved cell elongation, cell turgidity, opening of stomata and finally the partitioning of photosynthetic efficiently to the sink. This may have relatively more water stress at the critical stage of water requirement, as reflected in a decline in the plant growth parameters without mulch. Similar results have been reported by Sounda *et al.* (2006), Mathukia *et al.* (2014), Taufiq *et al.* (2017), Jain *et al.* (2018) and Kaur *et al.* (2020). Maximum yield attribute and yield per plant under residue mulch was mainly because this could be ascribed to the fact that moisture availability in the root zone increases the nutrient uptake which triggered the enhanced physiological effects which lead into increase in net assimilation followed by higher translocation of photosynthates from source to sink. Using crop residue mulch helps retain soil moisture by minimizing evaporation, which is particularly important in the hot summer months. These findings are in agreement with earlier reports of Ghosh *et al.* (2006), Mathukia *et al.* (2014), Ravisankar *et al.* (2014), Zayton *et al.* (2014), Patro and Ray (2016), Sarkar and Sarkar (2017), Jain *et al.* (2018), Maurya *et al.* (2019), Bhattarai *et al.* (2023) and Chaudhary *et al.* (2024).

Among Different stress mitigation chemicals salicylic acid @ 100 ppm at 45 and 60 DAS recorded significantly higher results and potassium nitrate @ 2 % and kaolin @ 6 % recorded comparable results to salicylic acid treatment in plant height, number of branches, dry matter production, number of pods per plant, pod yield and haulm yield of summer groundnut. Salicylic acid enhances photosynthesis and reduces oxidative damage, leading to increased plant height, dry matter production and crop growth rates by promoting cell division, elongation and metabolic activity. Potassium nitrate provides essential potassium and nitrogen, crucial for vegetative growth, resulting in increased plant height, more branches and higher dry matter accumulation due to better nutrient status and root development. Kaolin mitigates heat stress and conserves water by reflecting excess sunlight and reducing leaf temperature, thus maintaining turgor pressure and enhancing overall growth. Consequently, stress mitigation chemicals improved plant height and branching, with sustained dry matter production and growth rates even under suboptimal conditions. These findings are in conformity with those reported by Karimian *et al*. (2015) in green gram, Nezhad *et al*. (2014) and Nkrumah *et al*. (2021) in groundnut, Meenakshi and Prakash (2013) in soybean, Muthulakshmi and Lingakumar (2017) in pea and Singh *et al*. (2023) in coriander. Salicylic acid is known to enhance plant growth and productivity under stress by inducing systemic acquired resistance and activating defense-related enzymes. This leads to better stress tolerance and improved reproductive growth, resulting in a higher number of yield attribute and yield as compared to control. Salicylic acid likely improved the plant's ability to cope with abiotic stress conditions. Potassium nitrite and kaolin, though beneficial, operate differently. Potassium nitrite provides nutrient support and may improve stress resilience to some extent but is less effective than salicylic acid in enhancing reproductive traits. Kaolin acts as a physical barrier, reflecting sunlight and reducing heat stress, but does less directly influence internal physiological pathways as salicylic acid does. The efficacy of potassium nitrate spray @ 2% and kaolin spray @ 6%, which produced comparable results in individual years, suggests their role in mitigating stress through mechanisms like reduced transpiration and improved nutrient uptake, respectively. Consequently, the highest yield attributes observed with salicylic acid application is due to its ability to trigger internal defence mechanisms and improve overall plant health more effectively than potassium nitrite and kaolin. These findings are in conformity with those reported by Meena *et al*. (2017) in clusterbean, Thombare *et al*. (2017) and Nkrumah *et al*. (2021) in groundnut, Singh *et al*. (2023) in coriander and Raviteja *et al*. (2024) in maize.

The results from the present investigation clearly indicated that physiological traits *viz*, SPAD meter reading, relative water content and membrane stability index as well as water use efficiency of summer groundnut were significantly influenced by irrigation with residue mulch and stress mitigation chemicals during cropping period compared (Table 2).

Drip irrigation significantly affects physiological traits and water use efficiency. The more frequent and precise water application through drip irrigation can maintain better soil moisture conditions, which is crucial for optimal photosynthetic activity and chlorophyll development in groundnut leaves. Uniform distribution of water and nutrients through drip irrigation can result in more homogeneous crop growth and development, leading to consistent SPAD readings across the field compared to surface irrigation. Drip irrigation can help mitigate abiotic stresses like water deficit, which can negatively impact leaf chlorophyll levels. The improved water management under drip can enhance the resilience of the groundnut crop. Drip irrigation preserves higher RWC levels vital for plant health and resilience to abiotic stresses, establishing it as a superior strategy for enhancing crop resilience. Membrane Stability Index (MSI) assesses a plant's ability to withstand stress, with a higher MSI indicating healthier, more resilient plants. Drip irrigation targets water directly to the roots, ensuring consistent moisture and minimal waste, while surface irrigation inundates the soil, causing uneven water distribution and potentially waterlogged conditions. The benefits of drip irrigation encompass improved water use efficiency, soil moisture conditions, temperature consistency, salt control and nutrient accessibility. These results are in accordance with the findings of Yong-qiang *et* *al*. (2015), Soni *et al*. (2017), Pawar *et al*. (2018), Chomsang *et al*. (2021), Singh and Singh (2021) and Dong *et al*. (2023). Higher WUE under 0.6 PEF ($I_2$) might be due to less quantity of irrigation water application. Higher yield under 0.8 PEF ($I_3$) due to increase in moisture regimes increased the production of pod in proportion of consumptive use of water. Similar effect of irrigation on consumptive use of water and water use efficiency were observed by Rathore *et al*. (2018), Ranjitha *et al*. (2018), Mathukia *et al*. (2019), Kaur *et al*. (2020), Ramanjaneyulu *et al*. (2021), Harini *et al*. (2022) and Kumar *et al*. (2022).

The presence of mulch helps conserve soil moisture by reducing evaporation, which in turn maintains higher relative water content and SPAD meter reading in the plant leaves. Additionally, mulch insulates the soil, moderating temperature fluctuations and preventing excessive heating, which can damage cell membranes and improve the membrane stability index. The findings of Kannan *et al*. (2017), Singh *et al*. (2017), Chaithra and Sridhara (2018), Pradhan *et al*. (2018) and Das *et al*. (2019) are in agreement with these results. The increase in water use efficiency might be due to the greater pod yield due to application of residue mulch have minimum or moderate consumptive use of water and higher pod yield found. These findings are in conformity with those reported by Kadu *et al*. (2014), Jain *et al*. (2018), Maurya *et al*. (2017), Das *et al*. (2019) and Minh *et al*. (2023).

The results presented in the table 3 indicate that the application of stress alleviation chemicals, particularly salicylic acid @ 100 ppm and kaolin @ 6%, significantly improved leaf SPAD meter reading, relative water content and membrane stability index in summer groundnut at 90 DAS and at harvest compared to the control treatment of water spray. Specifically, Salicylic acid recorded the highest physiological traits at 90 DAS and at harvest across both years and in the pooled analysis. These findings suggest that salicylic acid and kaolin effectively mitigated abiotic stresses, likely by enhancing photosynthetic efficiency and leaf chlorophyll content, thereby improving the overall resilience of summer groundnut to environmental stresses. The lower physiological traits observed under the water spray treatment indicate reduced physiological traits compared to the stress alleviation chemicals. This suggests that water spray was not effective in mitigating abiotic stresses in summer groundnut, while salicylic acid and kaolin helped maintain higher chlorophyll levels and photosynthetic efficiency throughout the crop growth stages. The results support the potential of salicylic acid and kaolin as stress-alleviating agents to enhance the tolerance of groundnut to abiotic stresses. These findings are in conformity with those reported by Kong *et al*. (2015), Lakhran *et al*. (2021), Khavari *et al*. (2021), Meena *et al*. (2023) and Elshamly *et al*. (2024).

**Table 3. Effect of resilient strategies on physiological traits and water use efficiency of summer groundnut**

| Treatment | SPAD meter value | | RWC (%) | | MSI | | WUE |
|---|---|---|---|---|---|---|---|
| | 90 DAS | At harvest | 90 DAS | At harvest | 90 DAS | At harvest | (kg ha$^{-1}$ mm$^{-1}$) |
| **Irrigation (I)** | | | | | | | |
| **$I_1$** | 33.14 | 34.87 | 66.15 | 68.15 | 68.85 | 61.16 | 3.42 |
| **$I_2$** | 39.02 | 41.62 | 77.25 | 78.82 | 81.12 | 72.36 | 5.59 |
| **$I_3$** | 43.06 | 45.93 | 85.45 | 86.70 | 89.61 | 82.53 | 5.47 |
| **SEM** | 0.66 | 0.67 | 1.18 | 1.13 | 1.30 | 1.16 | 0.06 |
| **CD 5%** | 2.15 | 2.20 | 3.85 | 3.70 | 4.23 | 3.78 | 0.20 |
| **CV %** | 11.88 | 11.45 | 10.73 | 10.10 | 11.25 | 11.14 | 8.94 |
| **Residue Mulch (M)** | | | | | | | |
| **$M_0$** | 36.68 | 38.87 | 72.87 | 74.61 | 76.26 | 68.31 | 4.58 |
| **$M_1$** | 40.13 | 42.74 | 79.70 | 81.17 | 83.46 | 75.72 | 5.08 |
| **SEM** | 0.40 | 0.50 | 0.80 | 0.77 | 0.89 | 0.77 | 0.06 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **CD 5%** | | 1.24 | 1.54 | 2.48 | 2.38 | 2.75 | 2.36 | 0.17 |
| **CV %** | | 8.87 | 10.37 | 8.95 | 8.42 | 9.48 | 9.03 | 9.90 |
| **Stress Mitigation chemicals (S)** | | | | | | | | |
| **$S_0$** | | 35.15 | 37.06 | 69.96 | 71.81 | 73.08 | 65.95 | 4.46 |
| **$S_1$** | | 40.89 | 43.60 | 81.17 | 82.59 | 85.12 | 77.14 | 5.10 |
| **$S_2$** | | 37.53 | 39.73 | 74.60 | 76.27 | 78.01 | 70.48 | 4.91 |
| **$S_3$** | | 40.06 | 42.82 | 79.40 | 80.89 | 83.24 | 74.50 | 4.84 |
| **SEM** | | 0.48 | 0.56 | 0.98 | 0.94 | 1.01 | 0.91 | 0.07 |
| **CD 5%** | | 1.36 | 1.59 | 2.76 | 2.65 | 2.84 | 2.56 | 0.19 |
| **CV %** | | 7.51 | 8.28 | 7.70 | 7.25 | 7.57 | 7.57 | 8.21 |
| **I X M** | **SEM** | 0.70 | 0.86 | 1.39 | 1.34 | 1.55 | 1.33 | 0.10 |
| | **CD 5%** | 2.14 | 2.66 | 4.29 | 4.13 | 4.76 | 4.09 | 0.30 |
| **I X S** | **SEM** | 0.83 | 0.98 | 1.70 | 1.63 | 1.74 | 1.57 | 0.11 |
| | **CD 5%** | 2.35 | 2.75 | 4.78 | 4.60 | 4.92 | 4.43 | 0.32 |
| **M X S** | **SEM** | 0.68 | 0.80 | 1.38 | 1.33 | 1.42 | 1.28 | 0.09 |
| | **CD 5%** | 1.92 | 2.25 | 3.90 | 3.75 | 4.01 | 3.62 | 0.26 |
| **I X M X S** | **SEM** | 1.18 | 1.38 | 2.40 | 2.31 | 2.47 | 2.22 | 0.16 |
| | **CD 5%** | 3.32 | 3.89 | 6.76 | 6.50 | 6.95 | 6.27 | 0.46 |
| **Y** | **SEM** | 0.54 | 0.55 | 0.96 | 0.93 | 1.06 | 0.95 | 0.05 |
| | **CD 5%** | NS | NS | NS | NS | NS | NS | NS |

The maximum WUE was observed with the application of salicylic acid @ 100 ppm at 45 and 60 DAS, achieving values of 4.78, 5.41, and 5.10 kg $ha^{-1}$ $mm^{-1}$ for the years 2022, 2023 and pooled data, respectively. This improvement can be attributed to salicylic acid's role in enhancing plant stress tolerance by modulating physiological processes such as stomatal regulation and antioxidant activity, thereby improving water retention and utilization. Similarly, potassium nitrate @ 2% applied at the same intervals showed statistically comparable results, likely due to its beneficial effects on osmotic adjustment and nutrient uptake, which support better water use under stress. Kaolin spray at 6% also demonstrated significant efficacy by reducing leaf temperature and evapotranspiration, thus conserving soil moisture. In contrast, the lowest WUE was recorded with water spray, underscoring the lack of any protective effect against stress. These findings indicate that treatments with salicylic acid and potassium nitrate are particularly effective in improving WUE. These findings are in conformity with those reported by Krishna *et al.* (2018) and Alotaibi *et al*. (2023).

The prominent I x M x S interaction indicated that the concurrent application of these treatments drip irrigation at 0.8 PEF, residue mulch at 5 t $ha^{-1}$ and salicylic acid spray at 100 ppm resulted in superior outcomes, fostering environments that promoted heightened plant growth beyond the efficacy of individual treatments. This pattern of increased number of pods per plant and yield by improving the physiological traits and water use efficiency persisted consistently across both years and in the pooled data, underscoring the effectiveness of the integrated approach. The combination of these treatments creates a synergistic effect that optimizes multiple aspects of the plant's growing environment simultaneously. Drip irrigation ensures consistent water supply, mulch improves soil health and moisture retention and salicylic acid boosts the plant's stress tolerance and immune responses. This integrated approach results in a more stable and conducive environment for plant growth, leading to a higher yield.

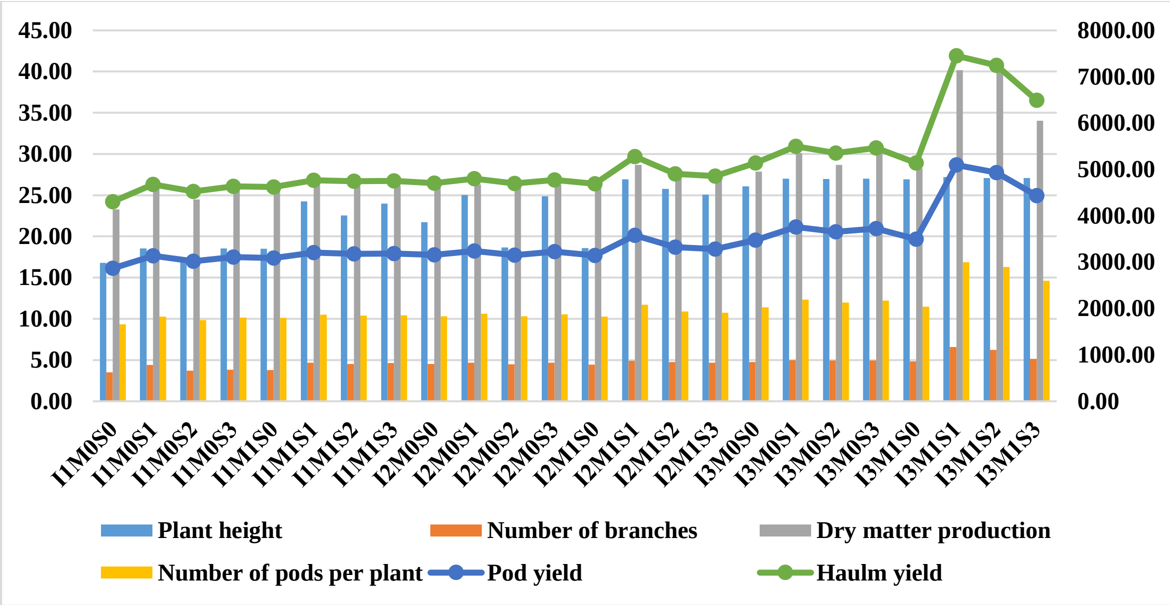


**Figure 1. Interaction effect of resilient strategies on plant height, number of branches per plant, dry matter production, number of pods per plant, pod and haulm yield of summer groundnut (pooled)**

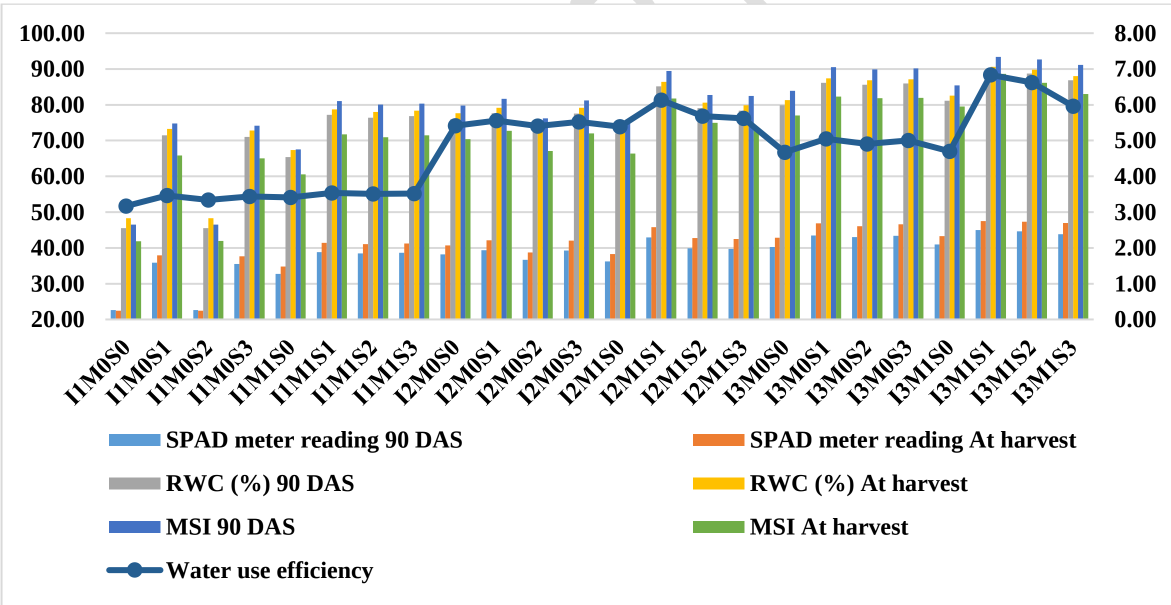


**Figure 2. Interaction effect of resilient strategies on physiological traits at 90 DAS & harvest and water use efficiency of summer groundnut (pooled)**

This comprehensive approach highlights the scientific rationale behind leveraging interactions among irrigation, mulching and stress mitigation chemicals to achieve sustained and improved crop productivity in agro-ecological contexts like the saurashtra region. These findings are in conformity with those reported by Patel *et al*. (2008), Kachhadiya *et al*. (2010), Kadu *et al*. (2014), Ravisankar *et al*. (2014), Majeed *et al*. (2016) , Dass and Bhattacharyya (2017), Kamble *et al*. (2017), Dass and Bhattacharyya (2017), Sanbagavalli *et al*. (2017), Tambe *et al*. (2017), Maurya *et al*. (2019), Swetha and Bhunia (2019), Bhatt *et al*. (2020), Athnere *et al*. (2020), Revathi *et al*. (2021), Yeganehpoor *et al*. (2021), Sharma *et al*. (2022) and Maurya *et al*. (2024).

The combination of drip irrigation at 0.8 PEF, residue mulch at 5 t ha$^{-1}$ and salicylic acid spray at 100 ppm ($I_3M_1S_1$) provided the highest economic returns and B: C ratios, highlighting the synergistic effects of these treatments. $I_3M_1S_1$ recorded gross realizations of ₹ 3,14,853 ha$^{-1}$ in 2022 and ₹ 3,38,966 ha$^{-1}$ in 2023, with net realizations of ₹ 2,37,526 ha$^{-1}$ and ₹ 2,62,423 ha$^{-1}$, and B: C ratios of 4.07 and 4.43 respectively. These results underscore the importance of integrated management practices in optimizing economic returns and resource use efficiency in summer groundnut cultivation. This might be due the higher benefits obtained under these treatments were also due to higher pod and haulm yields of summer groundnut. These findings are in vicinity with those reported by Kachhadiya *et al*. (2010), Kadu *et al*. (2014), Dass and Bhattacharyya (2017) and Sharma *et al*. (2022).



**Table 4. Effect of resilient strategies on economics of summer groundnut**

| Treatment | Cost of Cultivation (₹ ha$^{-1}$) | | Gross return (₹ ha$^{-1}$) | | Net return (₹ ha$^{-1}$) | | Benefit cost ratio | |
|---|---|---|---|---|---|---|---|---|
| | 2022 | 2023 | 2022 | 2023 | 2022 | 2023 | 2022 | 2023 |
| $I_1M_0S_0$ | 173855 | 194894 | 69880 | 68578 | 103974 | 126317 | 2.49 | 2.84 |
| $I_1M_0S_1$ | 192587 | 210754 | 69996 | 68694 | 122591 | 142061 | 2.75 | 3.07 |
| $I_1M_0S_2$ | 182179 | 206191 | 74212 | 72910 | 107967 | 133281 | 2.45 | 2.83 |
| $I_1M_0S_3$ | 191071 | 208593 | 95872 | 94570 | 95199 | 114023 | 1.99 | 2.21 |
| $I_1M_1S_0$ | 190893 | 206419 | 78145 | 76843 | 112747 | 129576 | 2.44 | 2.69 |
| $I_1M_1S_1$ | 196825 | 215067 | 78261 | 76959 | 118564 | 138108 | 2.51 | 2.79 |
| $I_1M_1S_2$ | 195855 | 212466 | 82477 | 81175 | 113378 | 131291 | 2.37 | 2.62 |
| $I_1M_1S_3$ | 196285 | 213028 | 104137 | 102835 | 92147 | 110193 | 1.88 | 2.07 |
| $I_2M_0S_0$ | 193826 | 212155 | 67101 | 66530 | 126725 | 145626 | 2.89 | 3.19 |
| $I_2M_0S_1$ | 198462 | 218213 | 67217 | 66645 | 131244 | 151568 | 2.95 | 3.27 |
| $I_2M_0S_2$ | 193631 | 211630 | 71433 | 70862 | 122198 | 140769 | 2.71 | 2.99 |
| $I_2M_0S_3$ | 198398 | 216093 | 93093 | 92522 | 105305 | 123571 | 2.13 | 2.34 |
| $I_2M_1S_0$ | 192761 | 211356 | 75366 | 74795 | 117394 | 136562 | 2.56 | 2.83 |
| $I_2M_1S_1$ | 216026 | 243567 | 75482 | 74910 | 140544 | 168657 | 2.86 | 3.25 |
| $I_2M_1S_2$ | 205296 | 221094 | 79698 | 79127 | 125598 | 141968 | 2.58 | 2.79 |
| $I_2M_1S_3$ | 202347 | 219008 | 101358 | 100787 | 100989 | 118222 | 2.00 | 2.17 |
| $I_3M_0S_0$ | 211762 | 235020 | 68946 | 68162 | 142817 | 166858 | 3.07 | 3.45 |
| $I_3M_0S_1$ | 227094 | 255927 | 69061 | 68278 | 158033 | 187649 | 3.29 | 3.75 |
| $I_3M_0S_2$ | 221863 | 247667 | 73278 | 72494 | 148585 | 175173 | 3.03 | 3.42 |
| $I_3M_0S_3$ | 226595 | 251844 | 94938 | 94154 | 131657 | 157690 | 2.39 | 2.67 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **$I_3M_1S_0$** | 212371 | 236955 | 77211 | 76427 | 135160 | 160528 | 2.75 | 3.10 |
| **$I_3M_1S_1$** | 314853 | 338966 | 77326 | 76543 | 237526 | 262423 | 4.07 | 4.43 |
| **$I_3M_1S_2$** | 297180 | 336277 | 81543 | 80759 | 215638 | 255518 | 3.64 | 4.16 |
| **$I_3M_1S_3$** | 267757 | 302007 | 103203 | 102419 | 164555 | 199588 | 2.59 | 2.95 |

Pod price = 58 ₹ kg$^{-1}$ (2022) & 63 ₹ kg$^{-1}$ (2023)

Haulm price = 2.5 ₹ kg$^{-1}$

## Conclusion

On the basis of the results obtained from the present two-years field study, it can be concluded that effective profitable production in summer groundnut can be obtained by application of two common surface irrigation (first immediately after sowing and second 5-6 days after first irrigation) each of 50 mm depth followed by scheduling drip irrigation at 0.8 PEF (operating pressure: 1.2 kg cm$^{-2}$ and lateral spacing: 90 cm) at alternate day with residue mulch @ 5 t ha$^{-1}$ and foliar application of stress mitigation chemicals like, salicylic acid @ 100 ppm or potassium nitrate @ 2% at 45 and 60 DAS under medium black calcareous soil of saurashtra region.

## Highlights

Enhanced growth and yield through drip irrigation at 0.8 PEF

Effectiveness of residue mulching at 5 t ha$^{-1}$

Impact of stress mitigation chemicals like salicylic acid, potassium nitrate and kaolin

Integrated agronomic practices for optimal results for resilient groundnut production

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