

# Impact of Salinity Stress on Soybean Growth and Yield under Saturated Soil Culture in Tidal Lands: A Comparative Study of Tolerant Varieties

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## Abstract

Salinity stress, intensified by climate change events such as El Niño and drought, presents a significant challenge to soybean production in tidal lands. This study evaluated soybean varieties' growth, tolerance, and yield under varying salinity conditions within a saturated water cultivation system. The experiment was conducted from February to May 2024 at the IPB Experimental Station in Leuwikopo, Bogor, Indonesia, using soil samples collected from type B tidal lands in Mulyasari Village, Banyuasin, South Sumatra. A completely randomized design (CRD) was employed with three factors and three replications each. The first factor was soybean variety ("Demas-1" and "Detap-1"), the second was soil salinity (0 and 2000 ppm NaCl), and the third was irrigation salinity at different growth stages (control, 2000 ppm NaCl before/during flowering, and 2000 ppm NaCl after flowering). The results demonstrated that the "Demas-1" variety exhibited superior growth characteristics, including higher leaf greenness, dry weight of root nodules, and number of filled pods per plant. Exposure to soil salinity of 2000 ppm NaCl led to a significant reduction in plant height (29.38%), leaf number (38.01%), leaf greenness (28.67%), dry weight (49.90%-60.80%), and filled pods per plant (55.51%), while increasing plant toxicity (108%). Irrigation with 2000 ppm NaCl further exacerbated these negative impacts, resulting in decreased leaf greenness (15.42%-18.06%) and filled pods per plant (17.84%-23.94%). The interaction between soybean variety, soil salinity, and irrigation salinity significantly influenced the number of filled pods per plant. The combination of any soybean variety with 2000 ppm NaCl resulted in a reduction of filled pods per plant. Moreover, applying saline irrigation after flowering to saline soil decreased the number of filled pods per plant by 64.68%. These findings highlight the critical

importance of selecting tolerant soybean varieties and implementing effective irrigation management strategies to mitigate the adverse effects of salinity on soybean production in tidal lands.

Keywords: El-Niño, leaf greenness, NaCl, seawater intrusion, tolerant

## Introduction

Salinity, a major environmental stressor, significantly impacts global agricultural productivity. Soil and irrigation water salinity substantially challenges plant growth and yield, particularly in coastal and arid regions. The primary causes of salinity include seawater intrusion into agricultural land and excessive use of saline water for irrigation (Mohanavelu et al., 2021). The El Niño phenomenon and prolonged droughts further exacerbate salinity problems by reducing freshwater flow and increasing seawater intrusion, intensifying plant salinity stress (Karuniasa and Pambudi, 2022; Susilawati et al., 2016).

Tidal lands, being sub-optimal land susceptible to salinity issues, are particularly affected by seawater intrusion. Increased salinity in tidal waters entering irrigation channels can lead to salt accumulation in the soil, disrupting plant water uptake and causing osmotic stress (Shrivastava and Kumar, 2015; Hanin et al., 2016). High salinity levels can also disrupt the balance of essential nutrients, leading to plant ion toxicity and nutrient deficiencies (Castillo et al., 2007; Zhao et al., 2010). The impact of salinity on plant performance varies depending on the plant's tolerance to salinity, the growth stage at which stress occurs, and the duration of stress (Ma et al., 2020).

Soybean, an important industrial food and non-food crop, is highly sensitive to salinity. Salinity can reduce plant biomass by 25-50% (Ilangumaran et al., 2021). Salinity stress in soybean cultivation on tidal lands can decrease growth and yield, especially during the early growth stage (Basuni, 2017). Effective development and implementation strategies should prioritize the use of tolerant soybean varieties to support optimal growth and production under saline conditions (Pujiwati et al., 2021). This approach must be complemented by precise water management practices, such as employing saturated soil culture technology and proper irrigation management. Saturated soil culture with water improvements has proven effective in increasing soybean production by maintaining soil saturation in tidal lands (Toyip et al., 2019).

Research focusing on the interaction between irrigation water salinity at different growth stages and soil salinity is crucial for understanding their combined effects on soybean growth and yield. It is also essential to identify soybean varieties that exhibit tolerance to salinity stress under saturated water cultivation. This study evaluates the growth, tolerance levels, and yield of different soybean varieties under salinity stress conditions in saturated water cultivation on tidal lands.

## Materials and Methods

The experiment was conducted from February to May 2024 under a plastic house at the IPB Experimental Station in Leuwikopo, Dramaga, Bogor, Indonesia. Soil samples were collected from type B tidal lands in Mulyasari Village, Banyuasin, South Sumatra. Plant fresh weight measurements were performed at the Leuwikopo Dry Laboratory, Department of Agronomy and Horticulture, IPB University.

A completely randomized design (CRD) was employed, incorporating three factors with three replications each. The first factor was soybean variety ("Demas-1" and "Detap-1"), the second factor was soil salinity (0 and 2000 ppm NaCl), and the third was irrigation salinity at different growth stages (continuous irrigation without 2000 ppm NaCl, with 2000 ppm NaCl for 15 days before and during flowering, and 2000 ppm NaCl for 15 days from flowering to pod formation). This resulted in 36 experimental units, each comprising three plants, totalling 108 plants.

### Experimental Procedures

Topsoil layers were collected from tidal land by separating the upper 0-10 cm and lower 10-20 cm.

The soil was air-dried and placed into 40 cm x 40 cm polybags, with 10 kg of soil per polybag. The topsoil was arranged according to the composition of soil layers. Manure and dolomite were applied to the soil two weeks before planting at a rate of 2 tons ha<sup>-1</sup> each. NaCl was applied to the soil along with dolomite and manure. Soybean were planted with two seeds per polybag. Polybags were placed inside plastic containers with a diameter of 39 cm. Irrigation was provided during planting by adding freshwater to the containers until the water level reached 5 cm from the bottom. The salinity treatment was applied by replacing the freshwater with saline water at a concentration of 2000 ppm NaCl in the containers, under the specified timing for each treatment. Following the conclusion of the salinity irrigation period, the saline water was replaced with fresh water. Urea was applied via foliar spraying at a concentration of 10 g.L<sup>-1</sup>, with a volume of 400 L.ha<sup>-1</sup> at 3, 4, 5, and 6 weeks after planting (Ghulamahdi et al., 2024). A total of 200 kg.ha<sup>-1</sup> of SP-36 (36% P<sub>2</sub>O<sub>5</sub>) and 100 kg.ha<sup>-1</sup> of KCl (60% K<sub>2</sub>O) were applied at the time of planting. Plant maintenance activities included replanting, pest control, and water level management. Soybeans were harvested when the plant leaves have fallen, and the pods are yellowish-brown with a moisture content of approximately 17-20%. (Sahuri, 2023).

### Plant Growth

Plant height and leaf number were measured on all plants at 8 weeks after planting (WAP).

### Plant Toxicity Levels

Plant toxicity was assessed based on the scoring method Pantalone et al. (1997), which evaluated the severity and number of leaves showing chlorosis at each plant during the R5 phase. The R5 phase is the pod-filling stage that occurs at eight weeks after planting (WAP), during which the highest levels of nitrogenase activity and nutrient absorption by the leaves are observed, followed by a decline in activity after the R5 phase (Ghulamahdi et al., 2006). The scale used for assessing plant toxicity is as follows: (1) no chlorosis, (2) mild (25% leaf chlorosis), (3) moderate (50% leaf chlorosis and necrosis), (4) severe chlorosis (75% of leaves showing severe chlorosis and necrosis), and (5) plant death, indicated by severe necrosis. The average toxicity score per experimental unit was calculated using the following formula:

$$\text{Plant toxicity level} = \frac{\sum(\text{LSsi}) (\text{number of plants})}{\text{Total number of plants per experimental unit}}$$

Note:  
LSsi = Score assessment: tolerant if the score  $\leq 2.0$   
and sensitive if the score  $\geq 3.0$

Range Test) if significant differences were found. Statistical analysis was performed using Microsoft Excel and R Studio software version 4.2.3.

### Leaf Greenness Levels

Leaf greenness levels were measured on fully mature leaves at the R5 growth stage using a SPAD 502plus meter (Konica Minolta).

### Crop Dry Weight

The dry weight of the plants was determined by weighing all parts of the plant, each root nodule, root, stem, and leaf, after drying in an oven at 80°C for 48 hours.

### Filled Pods Number per Plant

The number of filled pods per plant was determined by counting and summing each filled pod on every plant.

### Data Analysis

The research data were analyzed using ANOVA (Analysis of Variance) at a 95% confidence level ( $\alpha = 0.05$ ) and followed by the DMRT (Duncan Multiple

## Result and Discussion

### Plant Growth

There was no significant interaction effect on soybean growth between variety, soil salinity, and irrigation salinity. The variety and irrigation salinity at different growth stages did not significantly influence plant height and leaf number. However, soil salinity significantly affected plant height and leaf number (Table 1).

Adding 2000 ppm NaCl to the soil significantly reduced plant height and the leaf number by 29.38% and 38.01%, respectively, compared to 0 ppm NaCl eight weeks after planting (Table 1). High salinity concentrations in the growing medium cause stress inhibiting plant growth, preventing optimal development (Sihotang, 2021). The reduction in plant height and leaf number is primarily attributed to osmotic stress, as the plant struggles to absorb water. Furthermore, the toxic effects of Na and Cl ions inhibit cell division and enlargement (Romadloni

Table 1. Effect of variety, soil salinity, and irrigation salinity at different growth stages on plant height and leaf number at 8 WAP

Treatment	Plant height (cm)	Leaf number <sup>1</sup>
<b>Variety</b>		
“Demas-1”	67.7±3.82	14.0±0.14
“Detap-1”	60.5±6.54	14.3±0.27
P value	0.05	0.97
Sig.	ns	ns
<b>Soil salinity (ppm NaCl)</b>		
0	75.2±1.24 <sup>a</sup>	17.4±0.09 <sup>a</sup>
2000	53.0±3.50 <sup>b</sup>	10.8±0.09 <sup>b</sup>
P value	<0.01	<0.01
Sig.	**	**
<b>Irrigation salinity at different growth stages</b>		
Continuous irrigation	66.4±6.47	14.5±0.29
Irrigation with 2000 ppm NaCl for 15 days before and during flowering	65.1±6.09	14.0±0.20
Irrigation with 2000 ppm NaCl for 15 days, from flowering to pod formation	60.9±8.48	13.9±0.34
P value	0.45	0.89
Sig.	ns	ns

Note: Values followed by the same letter within the same column are not significantly different at the 5% level according to the DMRT test; \*\* = significant ( $\alpha = 0.01$ ); ns = not significant; <sup>1</sup>Data was transformed using the square root ( $\sqrt{x + 0.5}$ ); Mean values are followed by the standard error (s.e = 3).

and Wicaksono, 2018). The decrease in leaf number in plants subjected to salinity stress is an adaptive response to reduce water loss through evaporation due to the disruption of water and nutrient transport systems (Sobir et al., 2018).

#### Plant Toxicity Levels

There was no significant interaction effect on plant toxicity levels between variety, soil salinity, and irrigation salinity. However, individual treatment factors had significant effects. Neither variety nor irrigation salinity significantly impacted plant toxicity levels. In contrast, soil salinity significantly influenced plant toxicity levels (Table 2).

leaf chlorosis (Brown et al., 2006) The competition between Na<sup>+</sup> and Cl<sup>-</sup> ions with essential nutrient ions like NO<sub>3</sub><sup>-</sup> in saline soil further complicates nitrogen absorption by plant roots (Munns et al., 2019). Additionally, the nitrogen fixation process by symbiotic microorganisms is disrupted under saline conditions, leading to decreased nitrogenase enzyme activity.

#### Leaf Greenness Levels

Leaf greenness levels, an indicator of chlorophyll content, were significantly affected by variety, soil salinity, and irrigation salinity (Table 3). However, no

Table 2. Effects of variety, soil salinity, and irrigation salinity at different growth stages on the soybean plant toxicity levels

Treatment	Plant toxicity levels
<b>Variety</b>	
“Demas-1”	2.0±0.12
“Detap-1”	1.9±0.10
P value	0.44
Sig.	ns
<b>Soil salinity (ppm NaCl)</b>	
0	1.3±0.04 <sup>b</sup>
2000	2.6±0.06 <sup>a</sup>
P value	<0.01
Sig.	**
<b>Irrigation salinity at different growth stages</b>	
Continuous irrigation	1.7±0.14
Irrigation with 2000 ppm NaCl for 15 days before and during flowering	2.1±0.11
Irrigation with 2000 ppm NaCl for 15 days, from flowering to pod formation	2.0±0.16
P value	0.32
Sig.	ns

Note: Values followed by the same letter within the same column are not significantly different at the 5% level according to the DMRT test; \*\* = significant ( $\alpha = 0.01$ ); ns = not significant; Data was transformed using the square root ( $\sqrt{x + 0.5}$ ); Mean values are followed by the standard error (s.e = 3).

Soybeans grown in soil treated with 2000 ppm NaCl exhibited a significantly higher plant toxicity level, with a value of 2.63, which is 108% greater than those grown in soil treated with 0 ppm NaCl (Table 2). The study’s results indicate a strong correlation between the high level of toxicity experienced by plants in saline soil and the observed increase in leaf chlorosis. These findings align with the study by Xu and Mou (2016), which demonstrated that plants exposed to saline conditions exhibit higher chlorosis levels than those without saline stress. High soil salinity reduces the plant’s capacity to absorb water and nutrients, leading to nitrogen deficiency and subsequent

significant interaction effect was observed among the three factors.

The variety “Demas-1” exhibited significantly higher leaf greenness level, with a value of 33.65, which is 31.03% greater than that of “Detap-1” (Table 3). This difference in leaf greenness between varieties suggests that “Demas-1” has a better chlorophyll production capacity than “Detap-1”, likely due to genetic variation. Specific genes in plants can influence chlorophyll production efficiency, affecting leaf greenness by regulating chlorophyll synthesis, photosynthetic efficiency, and adaptation to light

Table 3. Effects of variety, soil salinity, and irrigation salinity at different growth stages on leaf greenness levels

Treatment	Leaf greenness levels
<b>Variety</b>	
“Demas-1”	33.65±0.23 <sup>a</sup>
“Detap-1”	25.68±0.25 <sup>b</sup>
P value	<0.01
Sig.	**
<b>Soil salinity (ppm NaCl)</b>	
0	34.63±0.20 <sup>a</sup>
2000	24.70±0.20 <sup>b</sup>
P value	<0.01
Sig.	**
<b>Irrigation salinity at different growth stages</b>	
Continuous irrigation	33.39±0.33 <sup>a</sup>
Irrigation with 2000 ppm NaCl for 15 days before and during flowering	28.24±0.40 <sup>b</sup>
Irrigation with 2000 ppm NaCl for 15 days, from flowering to pod formation	27.36±0.32 <sup>b</sup>
P value	<0.01
Sig.	**

Note: Values followed by the same letter within the same column are not significantly different at the 5% level according to the DMRT test; \*\* = significant ( $\alpha = 0.01$ ); ns = not significant; Data was transformed using the square root ( $\sqrt{x + 0.5}$ ); Mean values are followed by the standard error (s.e = 3).

intensity and environmental stress (Waititu et al., 2020; Wang et al., 2021; Dubey et al., 2021).

Soil salinity with the application of 2000 ppm NaCl significantly reduced leaf greenness by 28.67% compared to soil treated with 0 ppm NaCl (Table 3). This indicates that the chlorophyll content in plants grown in saline soil reduces photosynthetic efficiency. This reduction indicates that the chlorophyll content in saline soil decreases, reducing photosynthetic efficiency. The lower chlorophyll content in saline conditions is attributed to damage to cell and chloroplast structures caused by increased reactive oxygen species (ROS) production and decreased chlorophyll-synthesis enzyme activity (Wang et al., 2024; Sachdev et al., 2021). Increased salinity can impair the plant’s ability to absorb water and nutrients, reducing chlorophyll synthesis and affecting leaf greenness (Yan et al., 2022).

The application of irrigation with 2000 ppm NaCl from 15 days before flowering until flowering and from 15 days after flowering to pod formation significantly reduced leaf greenness levels by 15.42% and 18.06%, respectively, compared to continuous irrigation without 2000 ppm NaCl (Table 3). This suggests that salinity in irrigation at any phase of plant development can disrupt growth. When water conditions do not meet the plants requirements, metabolic processes at each growth stage are affected. Salinity in irrigation

directly impacts plant growth, with salinity during both the vegetative and generative phases reduces chlorophyll content and leaf greenness, ultimately affecting overall plant growth and yield (Saparsso et al., 2023).

#### Crop Dry Weight

The dry weight of plants is closely related to the utilization of photosynthates in plant organs. There was no significant interaction effect between variety, soil salinity, and irrigation salinity on the dry weight of root nodules. However, the soybean variety or soil salinity alone significantly affected plant dry weight. Irrigation salinity did not significantly impact any part of the plant’s dry weight (Table 4).

The “Demas-1” variety exhibited a significantly higher root nodule dry weight of 0.58 g, which is 114% greater than that of “Detap-1” (Table 4). This difference is likely due to genetic variations influencing the ability to form root nodules. Certain plant varieties can produce more extensive and more efficient root nodules in symbiosis with nitrogen-fixing bacteria (Wang et al., 2018). The physiological responses of different varieties to environmental stress and soil management also affect root nodule dry weight.



Figure 1. “Demas-1” with soil salinity and irrigation. A= 0 ppm NaCl in soil; B= 2000 ppm NaCl in soil; 1= continuous irrigation without 2000 ppm NaCl; 2= irrigation with 2000 ppm NaCl for 15 days before and during flowering; 3= irrigation with 2000 ppm NaCl for 15 days, from flowering to pod formation



Figure 2. “Detap-1” with soil salinity and irrigation. A= 0 ppm NaCl in soil; B= 2000 ppm NaCl in soil; 1= continuous irrigation without 2000 ppm NaCl; 2= irrigation with 2000 ppm NaCl for 15 days before and during flowering; 3= irrigation with 2000 ppm NaCl for 15 days, from flowering to pod formation

Soil salinity significantly impacted the dry weight of all parts of the plant. Soil treated with 2000 ppm NaCl resulted in a significantly lower dry weight of root nodules, roots, stems, and leaves by 54.24%, 60.80%, 52.58%, and 49.90%, respectively, compared to soil treated with 0 ppm NaCl (Table 4). Salinity stress disrupts the interaction between roots and rhizobium during root nodule initiation by impairing rhizobium attachment to the root surface and damaging the infection thread structure, which is essential for penetration, leading to poor root cell differentiation into nodules (Borucki and Sujkowska, 2008). This disruption in root nodule formation reduces nitrogen fixation efficiency and nutrient absorption (Abd-Alla et al., 2019). Salinity also impacts photosynthesis and allocation of photosynthates, and thereby reducing plant biomass accumulation (Otie et al., 2021).

Applying salinity in irrigation for 15 days from flowering to pod formation further reduces biomass weight. Salinity stress during flowering inhibits the

nitrogen fixation process in root nodules and nutrient absorption, resulting in suboptimal nutrient transport from the roots to the rest of the plant (Cordovilla et al., 1995). Leaves, a primary source for forming and filling pods, experience damage that reduces photosynthetic activity, thus lowering plant biomass weight (Lawson and Milliken, 2023; Zhang et al., 2020).

#### *Filled Pods Number per Plant*

The analysis of variance shows a significant interaction between the combination of variety and timing of salinity application in irrigation, as well as between soil salinity and irrigation salinity at different growth stages, on the number of filled pods per plant (Tables 6 and 7). All individual factors, namely variety, soil salinity, and irrigation salinity at different growth stages significantly affected the number of filled pods per plant (Table 5).

Table 4. Effects of variety, soil salinity, and irrigation salinity at different growth stages on plant dry weight

Treatment	Dry weight (g)			
	Root nodules	Roots	Stems	Leaves
<b>Variety</b>				
"Demas-1"	0.58±0.04a	2.78±0.06	5.74±0.06	3.96±0.05
"Detap-1"	0.27±0.04b	2.44±0.06	5.42±0.09	3.83±0.07
P value	<0.01	0.69	0.38	0.77
Sig.	**	ns	ns	ns
<b>Soil salinity (ppm NaCl)</b>				
0	0.59±0.04 <sup>a</sup>	3.75±0.02 <sup>a</sup>	7.57±0.06 <sup>a</sup>	5.19±0.05 <sup>a</sup>
2000	0.27±0.04 <sup>b</sup>	1.47±0.02 <sup>b</sup>	3.59±0.03 <sup>b</sup>	2.60±0.02 <sup>b</sup>
P value	<0.01	<0.01	<0.01	<0.01
Sig.	**	**	**	**
<b>Irrigation salinity at different growth stages</b>				
Continuous irrigation without 2000 ppm NaCl	0.46±0.08	2.81±0.05	6.66±0.10	4.78±0.08
Irrigation with 2000 ppm NaCl for 15 days before and during flowering	0.41±0.06	2.61±0.09	5.82±0.10	3.95±0.09
Irrigation with 2000 ppm NaCl for 15 days, from flowering to pod formation	0.40±0.06	2.42±0.07	4.26±0.06	2.95±0.02
P value	0.63	0.83	0.16	0.21
Sig.	ns	ns	ns	ns

Note: Values followed by the same letter within the same column are not significantly different at the 5% level according to the DMRT test; \*\* = significant ( $\alpha = 0.01$ ); ns = not significant; Data was transformed using the square root ( $\sqrt{x + 0.5}$ ); Mean values are followed by the standard error (s.e = 3).

The "Demas-1" variety produced the highest number of filled pods per plant, with 19.7 pods, which is 15.88% more than "Detap-1" (Table 5). This result is likely due to the variety's genetic capability to support more optimal pod formation and filling, leading to more filled pods.

Soil treated with 2000 ppm NaCl resulted in a significantly lower number of filled pods, with a 55.51% reduction than soil treated with 0 ppm NaCl (Table 5). Soil salinity reduces the number of filled pods by decreasing leaf chlorophyll content index and photosynthetic efficiency, leading to fewer pods, or underdeveloped, unfilled pods (Ibrahim et al., 2017).

Applying 2000 ppm salinity to irrigation 15 days before flowering and 15 days after flowering significantly reduced the number of filled pods per plant by 17.84% and 23.94%, respectively, compared to continuous irrigation without salinity (Table 5). Salinity in irrigation during both vegetative and generative phases negatively impacted pod filling. Salinity during the vegetative phase disrupts water and nutrient absorption, while salinity during the generative phase results in fewer or unfilled pods, reducing the overall number of filled pods (Liu and Suarez, 2021).

The analysis of variance also revealed a significant interaction between soybean varieties and soil salinity on the number of filled pods per plant. Both "Demas-1" and "Detap-1", when grown in soil treated with 2000 ppm NaCl, exhibited significantly lower pods number per plant, with reductions of 59.13% and 51.52%, respectively, compared to their counterparts grown in soil treated with 0 ppm NaCl (Table 6). This interaction indicates that environmental conditions and genetic characteristics influence production, with "Demas-1" being more sensitive to salinity, as evidenced by a more significant reduction in pod numbers than "Detap-1". Plant varieties with different genetic traits and tolerance levels respond differently to unfavorable conditions, affecting growth and yield. Sensitive varieties experience suboptimal growth, leading to inefficient photosynthesis and reduced plant productivity, ultimately decreasing the number of filled pods.

The analysis of variance revealed a significant interaction between soil salinity and irrigation salinity at different growth stages on the number of filled pods per plant. The combination of soil treated with 2000 ppm NaCl and irrigation with 2000 ppm NaCl from 15 days after flowering until post-flowering significantly reduced the number of filled pods per

Table 5. Effects of variety, soil salinity, and irrigation salinity at different growth stages on the filled pods number per plant

Treatment	Filled pod number per plant
<b>Variety</b>	
“Demas-1”	19.7±3.74a
“Detap-1”	17.0±3.14b
P value	<0.01
Sig.	**
<b>Soil salinity (ppm NaCl)</b>	
0	25.4±2.14b
2000	11.3±0.36a
P value	<0.01
Sig.	**
<b>Irrigation salinity at different growth stages</b>	
Continuous irrigation without 2000 ppm NaCl	21.3±5.20a
Irrigation with 2000 ppm NaCl for 15 days before and during flowering	17.5±4.22b
Irrigation with 2000 ppm NaCl for 15 days, from flowering to pod formation	16.2±3.45b
P value	<0.01
Sig.	**

Note: Values followed by the same letter within the same column are not significantly different at the 5% level according to the DMRT test; \*\* = significant ( $\alpha = 0.01$ ); Mean values are followed by the standard error (s.e = 3).

Table 6. Effects of the interaction between variety and soil salinity on the filled pods number per plant

Variety	Soil salinity (ppm NaCl)	Filled pod number per plant
“Demas-1”	0	27.9±1.44a
“Demas-1”	2000	11.4±0.61c
“Detap-1”	0	22.9±3.82b
“Detap-1”	2000	11.1±0.48c
P value		0.01
Sig.		*

Note: Values followed by the same letter within the same column are not significantly different at the 5% level according to the DMRT test; \* = significant ( $\alpha = 0.05$ ); Mean values are followed by the standard error (s.e = 3).

Table 7. Effects of the interaction between soil and irrigation salinity at different growth stages on the filled pods number per plant

Soil salinity (ppm NaCl)	Irrigation salinity at different growth stages	Filled pod number per plant
0	continuous irrigation without NaCl	30.3±0.00a
0	irrigation with 2000 ppm NaCl for 15 days before and during flowering	24.3±3.83b
0	irrigation with 2000 ppm NaCl for 15 days. from flowering to pod formation	21.5±0.33b
2000	continuous irrigation without NaCl	12.3±3.67c
2000	irrigation with 2000 ppm NaCl for 15 days before and during flowering	10.8±0.33c
2000	irrigation with 2000 ppm NaCl for 15 days. from flowering to pod formation	10.7±0.17c
P value		<0.01
Sig.		*

Note: Values followed by the same letter within the same column are not significantly different at the 5% level according to the DMRT test; \* = significant ( $\alpha = 0.05$ ); Mean values are followed by the standard error (s.e = 3).

plant by 64.68% compared to the combination of soil treated with 0 ppm NaCl and continuous irrigation without 2000 ppm NaCl (Table 7). Applying salinity to soil, irrigation, or both, decreases the number of filled pods per plant. This indicates that sub-optimal environmental conditions reduce the photosynthetic capacity and the translocation of assimilates to the organs responsible for pod formation and seed filling due to salinity stress. The adverse effects of salinity limit water and nutrient availability, disrupt hormonal imbalance and reduce photosynthesis, ultimately lowering the allocation of assimilates to reproductive tissues (Khan et al., 2023). Reduced photosynthesis efficiency leads to slower daily seed filling, resulting in fewer filled pods (Wahyuningsih et al., 2017). Salinity also causes a decline in vegetative and reproductive growth components during plant development in most leguminous plants. Furthermore, salinity increases fruit abscission rates and reduces the number of pods (Osman and Salim. 2016).

Soil salinity significantly impacts pod production more than irrigation water salinity. This suggests that soil salinity at the first planting stage makes newly planted seeds more vulnerable than salinity applied through irrigation during the juvenile phase. Salinity stress from the beginning of planting inhibits seed germination and the development of a robust root system (Wali et al., 2021). The reduced ability of plants to grow well during early growth directly affects yield, particularly in the form of fewer filled pods.

## Conclusion

The “Demas-1” variety demonstrated superior levels of leaf greenness, root nodule dry weight, and number of filled pods per plant but exhibited greater salinity sensitivity than “Detap-1”. Soil treated with 2000 ppm NaCl significantly reduced growth, leaf greenness, dry weight, and number of filled pods per plant, while increasing plant toxicity compared to 0 ppm NaCl. Similarly, irrigation with 2000 ppm NaCl, applied from 15 days before flowering until flowering, and from 15 days after flowering until post-flowering, reduced leaf greenness and the number of filled pods per plant compared to continuous irrigation without NaCl.

The interaction between variety and soil salinity, as well as the interaction between soil salinity and irrigation salinity, significantly affected the number of filled pods per plant. These interactions revealed that combining each soybean variety planted in soil treated with 2000 ppm NaCl led to fewer filled pods per plant than in soil treated with 0 ppm NaCl. Furthermore, combining

soil treated with 2000 ppm NaCl and irrigation with 2000 ppm NaCl from 15 days after flowering to pod formation resulted in a significantly lower number of filled pods per plant than soil treated with 0 ppm NaCl and continuous irrigation without NaCl. The combined effect of soil and irrigation water salinity reduced pod production per plant by 64.68%.

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## References

- Abd-Alla, M. H., Nafady, N. A., Bashandy, S. R., and Hassan, A.A. (2019). Mitigation of the effect of salt stress on the nodulation, nitrogen fixation, and growth of chickpea (*Cicer arietinum* L.) by triple microbial inoculation. *Rhizosphere* **10**, 1-11. DOI: <https://doi.org/10.1016/j.rhisph.2019.100148>
- Basuni. (2017). “Respon Morfofisiologi Tanaman Jagung terhadap Tingkat Salinitas dan Amelioran pada Sistem Budidaya Jenuh Air di Lahan Sulfat Masam”. [Thesis]. Fakultas Pertanian, IPB University.
- Borucki, W., and Sujkowska, M. (2007). The effects of sodium chloride-salinity upon growth, nodulation, and root nodule structure of pea (*Pisum sativum* L.) plants. *Acta Physiologiae Plantarum* **30**, 293–301. DOI: <https://doi.org/10.1007/s11738-007-0120-8>
- Brown, C.E., Pezeshki, S.R., and DeLaune, R.D. (2006). The effects of salinity and soil drying on nutrient uptake and growth of *Spartina alterniflora* in a simulated tidal system. *Environmental and Experimental Botany* **58**, 140–148. DOI: <https://doi.org/10.1016/j.envexpbot.2005.07.006>
- Castillo, E.G., Tuong, T.P., Ismail, A.M., and Inubushi, K. (2007). Response to salinity in rice: comparative effects of osmotic and ionic stresses. *Plant Production Science* **10**, 159-170. DOI: <https://doi.org/10.1626/pps.10.159>
- Cordovilla, M.P., Ocaña, A., Ligeró, F., and Lluch, C. (1995). Salinity effects on growth analysis and nutrient composition of grain

- legumes-rhizobium symbiosis. *Journal of Plant Nutrition* **18**, 1595–1609. <https://doi.org/10.1080/01904169509365006>
- Dubey, A.K., Khatri, K., Jha, B., and Rathore, M.S. (2021). The novel galactosyl transferase-like (SbGalT) gene from *Salicornia brachiata* maintains photosynthesis and enhances abiotic stress tolerance in transgenic tobacco. *Gene* **786**, 1-17. DOI: <https://doi.org/10.1016/j.gene.2021.145597>
- Ghulamahdi, M., Aziz, S.A., Lubis, I., Abimanyu, B., Shiraiwa, T., and Taylor, P. (2024). Effect of planting distance and foliar fertilizer on soybean growth and yield in saturated soil culture in tidal swamp. *Universal Journal of Agricultural Research* **12**, 539-545. DOI: <https://doi.org/10.13189/ujar.2024.120401>
- Ghulamahdi, M., Aziz, S.A., Melati, M., Dewi, N., and Rais, S.A. (2006). Aktivitas nitrogenase, serapan hara dan pertumbuhan dua varietas kedelai pada kondisi jenuh air dan kering. *Buletin Agronomi* **34**, 32-38. <https://journal.ipb.ac.id/index.php/jurnalagronomi/article/view/1272/376>
- Hanin, M., Ebel, C., Ngom, M., Laplaze, L., and Masmoudi, K. (2016) New insights on plant salt tolerance mechanisms and their potential use for breeding. *Frontiers in Plant Science* **7**, 1-17. DOI: <https://doi.org/10.3389/fpls.2016.01787>
- Ibrahim, W., Ahmed, I.M., Chen, X., and Wu, F. (2017). Genotype-dependent alleviation effects of exogenous GSH on salinity stress in cotton is related to improvement in chlorophyll content, photosynthetic performance, and leaf/root ultrastructure. *Environmental Science and Pollution Research* **24**, 9417-9427. <https://doi.org/10.1007/s11356-017-8611-7>
- Ilangumaran, G., Schwinghamer, T.D., and Smith, D.L. (2021) Rhizobacteria from root nodules of an indigenous legume enhance salinity stress tolerance in soybean. *Frontiers in Sustainable Food Systems* **4**, 1-18. DOI: <https://doi.org/10.3389/fsufs.2020.617978>
- Karuniasa, M., and Pambudi, P.A. (2022). The analysis of the El Niño phenomenon in the East Nusa Tenggara Province, Indonesia. *Journal of Water and Land Development* **52**, 180-185. DOI: <http://dx.doi.org/10.24425/jwld.2022.140388>
- Khan, F., Siddique, A.B., Shabala, S., Zhou, M., and Zhao, C. (2023). Phosphorus plays key roles in regulating plants physiological responses to abiotic stresses. *Plants* **12**, 1-29. <https://doi.org/10.3390/plants12152861>
- Lawson, T., and Milliken, A.L. (2023). Photosynthesis – beyond the leaf. *New Phytologist* **238**, 55–61. DOI: <https://doi.org/10.1111/nph.18671>
- Liu, X., and Suarez, D.L. (2021). Lima bean growth, leaf stomatal and nonstomatal limitations to photosynthesis, and <sup>13</sup>C discrimination in response to saline irrigation. *Journal of the American Society for Horticultural Science* **146**, 132-144. DOI: <https://doi.org/10.21273/JASHS04996-20>
- Ma, Y., Dias, M., and Freitas, H. (2020). Drought and salinity stress responses and microbe-induced tolerance in plants. *Frontiers in Plant Science* **11**, 1-18. <https://doi.org/10.3389/fpls.2020.591911>
- Mohanavelu, A., Naganna, S.R., and Al-Ansari, N. (2021). Irrigation induced salinity and sodicity hazards on soil and groundwater: An overview of its causes, impacts, and mitigation strategies. *Agriculture* **11**, 1-17. DOI: <https://doi.org/10.3390/agriculture11100983>
- Munns, R., Day, D.A., Fricke, W., Watt, M., Arsova, B., Barkla, B.J., Bose, J., Byrt, C.S., Chen, Z., Foster, K.J., et al. (2019). Energy costs of salt tolerance in crop plants. *New Phytologist* **225**, 1072-1090. <https://doi.org/10.1111/nph.15864>
- Osman, H.S., and Salim, B.B.M. (2016). Influence of exogenous application of some phytoprotectants on growth, yield, and pod quality of snap bean under NaCl salinity. *Annals of Agricultural Sciences* **61**, 1–13. DOI: <https://doi.org/10.1016/j.aosas.2016.05.001>
- Otie, V., Udo, I., Shao, Y., Itam, M.O., Okamoto, H., An, P., and Eneji, E.A. (2021). Salinity effects on morpho-physiological and yield traits of soybean (*Glycine max* L.) as mediated by foliar spray with brassinolide. *Plants* **10**, 1-22. <https://doi.org/10.3390/plants10030541>
- Pantalone, V., Kenworthy, W., Slaughter, L.H., and James, B.R. (1997). Chloride tolerance in soybean and perennial *Glycine* accessions. *Euphytica* **97**, 235–239. DOI: <https://doi.org/10.1023/A:1003068800493>
- Pujiwati, H., Suharjo, U.J.K., Prameswari, W., Husna, Siti Nurminah Nasution, Munif Ghulamahdi, Maya Melati

- M., Murcitra, B.G., Ginting, S., and Susilo, E. (2021). Morphological and physiological performances of 18 soybean varieties exposed to salinity stress. *Jurnal Agronomi Indonesia* **49**, 251-258. DOI: <https://dx.doi.org/10.24831/jai.v49i3.37819>
- Romadloni, A., and Wicaksono, K.P. (2018). Pengaruh beberapa level salinitas terhadap perkecambahan kacang hijau (*Vigna radiata* L.) varietas Vima 1. *Jurnal Produksi Tanaman* **6**, 1663-1670. <https://protan.studentjournal.ub.ac.id/index.php/protan/article/view/825>
- Sachdev, S., Ansari, S.A., Ansari, M.I., Fujita, M., Hasanuzzaman, M. (2021). Abiotic stress and reactive oxygen species: generation, signaling, and defense mechanisms. *Antioxidants* **10**, 1-37. DOI: <https://doi.org/10.3390/antiox10020277>.
- Sahuri. (2023). "Efisiensi Lahan dan Waktu Tanam Sisip Jagung pada Beberapa Varietas Kedelai dengan Budidaya Jenuh Air di Lahan Pasang Surut." [Thesis]. Fakultas Pertanian, IPB University.
- Saparso, Sudarmaji, A., and Musthafa, M.B. (2023). Physiological aspects of the growth of corns (Bonanza 9-F1 and Bisi-18) to air aalinity conditions on coastal area In "Proceedings of the 3<sup>rd</sup> International Conference on Sustainable Agriculture for Rural Development (ICSARD 2022)" (S.B. Sulistyio et al., eds.), pp 362-372, Jawa Tengah, Indonesia. Atlantis Press.
- Shrivastava, P., and Kumar, R. (2015). Soil salinity: a serious environmental issue and plant growth promoting bacteria as one of the tools for its alleviation. *Saudi Journal of Biological Sciences* **22**, 123-131. DOI: <https://doi.org/10.1016/j.sjbs.2014.12.001>
- Sihotang, T. (2021). Pengaruh cekaman salinitas terhadap pertumbuhan tanaman semusim. *Fruitset Sains: Jurnal Pertanian Agroteknologi* **9**, 45-51. <https://www.ejournal.iocscience.org/index.php/Fruitset/article/download/1813/1468/5785>
- Sobir, Miftahudin, and Helmi, S. (2018). Respon morfologi dan fisiologi genotipe terung (*Solanum melongena* L.) terhadap cekaman salinitas. *Jurnal Hortikultura Indonesia* **9**, 131-138. <https://doi.org/10.29244/jhi.9.2.131-138>
- Susilawati, A., Nursyamsi, D., and Syakir, M. (2016). Optimalisasi penggunaan lahan rawa pasang surut mendukung swasembada pangan nasional. *Jurnal Sumberdaya Lahan* **10**, 51-64.
- Toyip, Ghulamahdi, M., Sopandie, D., Aziz, S.A., Sutandi, A., and Purwanto, M.Y.J. (2019). Physiological responses of four soybean varieties and their effect on yield in several saturated soil culture modification. *Biodiversitas* **20**, 2266-2272. DOI: <https://doi.org/10.13057/biodiv/d200822>
- Wahyuningsih, S., Kristiono, A., and Taufiq, A. (2017). Pengaruh jenis amelioran terhadap pertumbuhan dan hasil kacang hijau di tanah salin. *Buletin Palawija* **15**, 69-77.
- Waititu, J.K., Zhang, C., Liu, J., and Wang, H. (2020). Plant non-coding RNAs: origin, biogenesis, mode of action and their roles in abiotic stress. *International Journal of Molecular Sciences* **21**, 1-22. DOI: <https://doi.org/10.3390/ijms21218401>
- Wang, F., Sun, H., Rong, L., Li, Z., An, T., Hu, W., and Ye, Z. (2021). Genotypic-dependent alternation in D1 protein turnover and PSII repair cycle in psf mutant rice (*Oryza sativa* L.), as well as its relation to light-induced leaf senescence. *Plant Growth Regulation* **95**, 121-136. DOI: <https://doi.org/10.1007/s10725-021-00730-8>
- Wang, Q., Liu, J., and Zhu, H. (2018). Genetic and molecular mechanisms underlying symbiotic specificity in legume-rhizobium interactions. *Frontiers in Plant Science* **9**, 1-8. DOI: <https://doi.org/10.3389/fpls.2018.00313>
- Wang, X., Chen, Z., and Sui, N. (2024) Sensitivity and responses of chloroplasts to salt stress in plants. *Frontiers in Plant Science* **15**, 1-11. DOI: <https://doi.org/10.3389/fpls.2024.1374086>
- Wali, S.U., Gada, M.A., Umar, K.J., Abba, A., and Umar, A. (2021). Understanding the causes, effects, and remediation of salinity in irrigated fields: a review. *International Journal of Agriculture and Animal Production* **1**, 9-42. DOI: <https://doi.org/10.55529/ijaap.11.9.42>
- Xu, C., and Mou, B. (2016). Responses of spinach to salinity and nutrient deficiency in growth, physiology, and nutritional value. *Journal of the American Society for Horticultural Science* **141**, 12-21. DOI: <https://doi.org/10.21273/JASHS.141.1.12>

- Yan, S., Chong, P., and Zhao, M. (2022). Effect of salt stress on the photosynthetic characteristics and endogenous hormones: a comprehensive evaluation of salt tolerance in *Reaumuria soongorica* seedlings. *Plant Signaling and Behavior* **17**, 1-15. DOI: <https://doi.org/10.1080/15592324.2022.2031782>
- Zhang, Y., Kaiser, E., Marcelis, L.F.M., Yang, Q., and Li, T. (2020). Salt stress and fluctuating light have separate effects on photosynthetic acclimatization, but interactively affect biomass. *Plant, Cell, and Environment* **43**, 2192-2206. <https://doi.org/10.1111/pce.13810>
- Zhao, K.F., Song, J., Fan, H., Zhou, S., and Zhao, M. (2010). Growth response to ionic and osmotic stress of NaCl in salt-tolerant and salt-sensitive maize. *Journal of Integrative Plant Biology* **52**, 468-475. DOI: <https://doi.org/10.1111/j.1744-7909.2010.00947.x>