Evaluation of soybean tolerance to soil salinity

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Abstract. Climate change poses weather pattern and heat stress on the soil, along with the sea-level rise and groundwater depletion lead to the expansion of soil salinity hazard on arable lands and turn it to saline-prone lands. In Indonesia, soybean profitability and competitiveness over rice and maize are relatively lower leads to the lesser priority in the development. Further, the cultivation area is declined and start utilizing suboptimal lands, including saline-prone lands. Salinity affects soybean productivity; therefore, the use of salinity-tolerant varieties is key to successful soybean cultivation in saline soils. The study was carried out to evaluate the tolerance of soybean varieties under salinity stress. The experiment was conducted at saline field in Lamongan during 2017 dry season. Forty-one soybean varieties were evaluated based on their responses under salinity stress. Research observations included soil electrical conductivity as the salinity measure, plant growth parameters, yield components, and yield. The data were analysed using descriptive statistics and the tolerance to salinity stress was assessed based on Stress Tolerance Index (STI). Evaluated soybean varieties performed various responses to different salinity levels, both in terms of growth and yield parameters. In general, lesser results were observed for most parameters at higher salinity level. Based on the value of STI, 7 varieties were tolerant to salinity but only 2 among them showed yield productivity of >1.5 t ha⁻¹, i.e., Dena 1 and Lokon. Both varieties are very potential to be used as high-yielding parents for salinity tolerant soybean breeding programs.

1. Introduction

Climate change poses weather pattern and heat stress on the soil, along with the sea-level rise and groundwater depletion lead to the expansion of soil salinity hazard on arable lands and turn it to saline-prone lands. Among various environmental stresses, soil salinity has become a critical problem worldwide due to its dramatic effects on plant physiology and performance [1].

Salinity affects soybean growth since early stage of plant germination to generative phase. It delays germination, and under severe condition even results in failure of seeds to germinate [2], decreases sprout vigor index [3], and afterwards inhibits plant growth during vegetative phase [4]. This suggests the importance of salinity-tolerant varieties for successful soybean cultivation in saline soils.

The varietal differences in salinity tolerance that exist among crop plants, including soybean, can be utilized through screening programs by exploiting appropriate traits for salt tolerance [5]. The use of physiological tolerance along with agronomic traits has been shown to be applicable and their relationship with salt tolerance indices are considered strong enough to be exploited as a selection tool in the breeding of salt tolerance cultivars [6]. The present study was carried out to evaluate the tolerance of soybean varieties under salinity stress.
2. Materials and method

The study was conducted at saline field in Lohgung Village, Berondong Sub District, Lamongan (6°53'59.89"S and 112°11'15.31"E; 26 m asl) (Figure 1). Soil salinity at the site was considered as slightly-to-moderately saline based on the classification by USDA [7] with EC ranged from 4 to 16 dS m⁻¹, which this group of classification with yields of many crops described as restricted and only tolerant crops yield satisfactory [8].

![Figure 1. Site of experiment in Lamongan District, East Java, Indonesia.](image)

The experiment was based on observations on 41 soybean varieties responses (Table 1) evaluated at three sites with different levels of salinity within Lohgung Village. The experiment was arranged following unreplicated soybean germplasm characterization regularly performed for early screening. Each variety was planted on a single 4 m long plot, 30 cm x 15 cm planting distance, with 2-3 seeds/hill.

Before planting, the land was cleared from weeds and previous crop residues, then plowed with rotary machine and flattened. Soybean seeds are planted following tugal system. Basal fertilizer applied consisted of 250 kg ha⁻¹ Phonska + 100 kg ha⁻¹ SP36 + 2.5 t ha⁻¹ manufactured organic fertilizer. Second fertilizer application consisted of 100 kg ha⁻¹ Urea applied 15 days after planting (DAP), prior to the first weeding. Thinning was done at 14 DAP, leaving 2 plants/hill. Weeding was done manually at 50 DAP. Irrigation was given five times, i.e. right after planting and at 17, 38, 46, 66, and 82 DAP. The irrigation source was from wells around the study site with EC ranged 3.8–4.0 dS m⁻¹ and pH 6.9–7.5. Pest control was carried out preventively by applying chemical insecticides as needed.

Harvest was done manually soon after the pods physiological maturity, i.e. when at least one pod on the main stem has turned brown. Due to different maturity days between varieties, the harvest was carried out gradually at 81, 87, and 93 DAP.

Research observations included soil EC, plant growth parameters, and yield components. Soil EC was observed three times, i.e. at planting, 15–20 DAP, and 45–55 DAP. EC measurement was done directly in the field at 0–15 cm soil depth using a portable EC meter. Only EC data from 45 DAP was used for further data analysis. Plant growth parameters were observed at 15 DAP, 45 DAP, and right before harvest by counting the number of plants per plot and measuring plant height, however, for further data analysis only plant population number at 15 DAP and at harvest were used to calculate population decrease, as well as plant height. Observations at harvest were carried out for number of filled pods, weight of 100 seeds, and yield.
Table 1. Soybean varieties evaluated in the study.

| No. | Accession Code | Variety Name   | No.   | Accession Code | Variety Name   |
|-----|---------------|----------------|-------|---------------|----------------|
| 1   | MLGG 1085     | Baluran        | 22    | MLGG 1082     | Lawit          |
| 2   | MLGG 1061     | Cikuray        | 23    | MLGG 1070     | Leuser         |
| 3   | MLGG 603      | Davros         | 24    | MLGG 767      | Lokon          |
| 4   | MLGG 1109     | Dega 1         | 25    | MLGG 1054     | Lumajang Bewok |
| 5   | MLGG 1106     | Den a 1        | 26    | MLGG 1083     | Menyapa        |
| 6   | MLGG 1107     | Den a 2        | 27    | MLGG 796      | Merbabu        |
| 7   | MLGG 1103     | Dering 1       | 28    | MLGG 795      | Muria          |
| 8   | MLGG 1098     | Detam 2        | 29    | MLGG 1093     | Mutiara        |
| 9   | MLGG 1101     | Detam 3        | 30    | MLGG 674      | No. 27         |
| 10  | MLGG 1102     | Detam 4        | 31    | MLGG 0029     | Orba           |
| 11  | MLGG 1056     | Dieng          | 32    | MLGG 1067     | Pangrango      |
| 12  | MLGG 1104     | Gamasugen 1    | 33    | MLGG 1089     | Ratai          |
| 13  | MLGG 1105     | Gamasugen 2    | 34    | MLGG 0031     | Ringgit        |
| 14  | MLGG 1096     | Gema           | 35    | MLGG 801      | Rinjani        |
| 15  | MLGG 1095     | Gepak Kuning   | 36    | MLGG 1088     | Seulawah       |
| 16  | MLGG 1099     | Grobogan       | 37    | MLGG 1075     | Sinabung       |
| 17  | MLGG 0032     | Guntur         | 38    | MLGG 1062     | Singgalang     |
| 18  | MLGG 1086     | Ijen           | 39    | MLGG 1066     | Slamet         |
| 19  | MLGG 1076     | Kaba           | 40    | MLGG 572      | Tampomas       |
| 20  | MLGG 0096     | Kerinci        | 41    | MLGG 1060     | Tampomas       |
| 21  | MLGG 1059     | Krakatau       |       |               |                |

The data were analyzed using descriptive statistics and the tolerance of stress was assessed based on Stress Tolerance Index (STI) [9]. The STI considers both stress tolerance and yield potentials. The STI is estimated as:

\[
\text{STI} = \frac{Y_{pi} \times Y_{si}}{Y_p^2}
\]

where:

- \(Y_{pi}\) = yield of certain variety obtained from no or less stressed environment
- \(Y_{si}\) = yield of certain variety obtained from stressed environment
- \(Y_p\) = average yield of all varieties obtained from no or less stressed environment

The higher the value of STI for a genotype in a given stressed environment, the higher was its stress tolerance and yield potential. Genotypes with STI ≤0.5 is classified sensitive, 0.5<STI≤1.0 moderately tolerant, and STI>1.0 tolerant.

3. Results and discussion

3.1. Results

In terms of soil salinity as indicated by the value of electrical conductivity (EC) measured at 45 DAP, it was seen that site 1 (S1) had a relatively lower EC value than the other two sites (S2 and S3) (Figure 2). Soybean is sensitive to salinity, but its sensitivity varies between genotypes. However, generally accepted that the critical limit of soybean yield loss due to salinity is at 5 dS m\(^{-1}\) [10], and, therefore, the sites of the present study provided relatively higher salinity stresses to soybean varieties tested. The mean EC values on S1, S2, and S3 were 6.27, 13.35, and 12.92 dS m\(^{-1}\), respectively (Table 2).
Increased soil EC as observed from S1 to S3 and S2 lead to variation of plant population decrease observed from 15 DAP to harvest (Table 2). All varieties experienced population decrease in S1, while in S2 and S3 some of varieties showed no decrease and even population increase. Most varieties experienced population decrease >25% at the lowest salinity level (S1). Whereas at the higher salinity level (S2 and S3) the most population decrease varieties were found to be in the range of 10-25% and there were 8 varieties showed no population decrease; 2 varieties in S2 only (Detam 3 and Gamasugen 1), 4 varieties in S3 only (Orba, Ratai, Sinabung, and Slamet), and 1 variety (Ijen) in both S2 and S3. This result was quite encouraging considering that one indicator of plant tolerance to soil salinity stress...
is its ability to survive and from observations appears that most genotypes have decreased population numbers <25% at higher salinity level. Previous study recommends 25% as the population decrease limit for salinity tolerant soybeans [11].

In general, plant height decreases with increasing salinity. This can be seen from the average plant height observed at S1 (EC = 6.27 dS m\(^{-1}\)), S3 (EC = 12.92 dS m\(^{-1}\)), and S2 (EC = 13.35 dS m\(^{-1}\)) were 71.6 cm, 68.9 cm and 66.3 cm, respectively (Table 2). Based on the range, the variety in S1 shows the largest where the plant height ranges from 42.7-101.7 cm, while the variety in S3 ranges from 47.3-100.3 cm and in S2 ranges from 48.3-91.3 cm. Considering the lowest salinity level at S1 and the highest at S2, evaluated varieties can be grouped into 2, those are varieties that have decreased plant height with increasing salinity (lower plant height at S2 compared to that of S1) and varieties that have increased plant height with increasing salinity (higher plant height at S2 compared to that of S1). It was observed from this study there were 17 out of 41 varieties grew taller at higher level of soil salinity (Figure 3).

Number of filled pods between sites showed a similar trend to plant height, where the highest value was obtained in S1, followed by S3 and S2, with averages of 49.3, 37.04, and 33.07, respectively (Table 2). The number of filled pods in S1–S3 ranges from 15.33–107.33, 12–70.67, and 10–73.33, respectively. It was observed from present study there were 8 varieties showed increased number of filled pods at higher salinity levels, i.e, Gamasugen 1, Singgalang, Lumajang Bewok, Dering 1, Dering 4, Sinabung, Ringgit, and Lokon. Those varieties showed an increase in number of filled pods ranging from 21.30–111.60% (Figure 4).

The 100-seed weight observed in this study showed a similar trend to previous parameters where the highest value was obtained at S1 (9.1 g) and the lowest at S2 (6.9 g). The range of 100-seeds weight in S1–S3 are 5.3–16.2 g, 3.7–13.6 g, and 3.4–17.4 g, respectively (Table 2). And there was only one variety increased 100-seeds weight at higher level of soil salinity, i.e., Detam 3 (Figure 5). Previous study grouped soybean size based on its 100-seeds weight of 8-10 grams, 10-13 gram, and >13 gram into...
small, medium, and big, respectively [12]. Based on the grouping, the seeds of all varieties tested in this study were small-to-very small sized.

**Figure 4.** Distribution among varieties (X axis) of number of filled pods decrease (Y axis, negative values) or increase (Y axis, positive values) from lowest to highest salinity level (%). Only varieties showed number of filled pods increase are labelled.

**Figure 5.** Distribution among varieties (X axis) of 100-seeds weight decrease (Y axis, negative values) or increase (Y axis, positive values) from lowest to highest salinity level (%). Only variety showed 100-seeds weight increase is labelled.

The varieties evaluated showed relatively low yields (lower than the national soybean productivity of 1.44 t ha$^{-1}$) at all three levels of salinity. Yield productivity shown from the lowest to highest salinity...
is 1.33, 1.07, and 0.72 t ha\(^{-1}\), respectively (Table 2). However, in terms of yields per variety, there were 2 varieties with productivity >1.5 t ha\(^{-1}\), both at low salinity and high salinity (Figure 6). Those varieties were Lokon and Dena 1, which yielded 1.76 and 1.59 t ha\(^{-1}\), respectively, at the highest salinity level in this study. With respect to their decreasing yields productivity from lowest to highest salinity level, Dena 1 showed lesser yield decrease (<10%) compared to that of Lokon (>20%).

![Figure 6](image_url)

**Figure 6.** Comparison of soybean yields productivity at two contrasting levels of salinity in the study.

Based on the stress tolerance index (STI), 19 varieties were classified as sensitive, 15 moderately tolerant, and 7 tolerant to salinity stress (Figure 7). Lokon, Dieng, Dena 1, Detam 2, Sinabung, Guntur, and Baluran were those seven varieties that tolerant to salinity with STI values of 2.27, 1.67, 1.57, 1.48, 1.14, 1.12, and 1.06, respectively. Of these seven varieties, as discussed earlier, only Lokon and Dena 1 yielded >1.5 t ha\(^{-1}\) at high salinity. The other five varieties although showing STI values categorized as tolerant, but their productivity was still relatively low at higher salinity.

![Figure 7](image_url)

**Figure 7.** Distribution of the stress tolerance index (STI) to salinity stress of 41 soybean varieties.
3.2. Discussion

Evaluated soybean varieties performed various responses to different salinity level observed in the present study, both in terms of growth and yield parameters. In general, lesser results was observed for all parameters at higher salinity level, except for population decrease which showed slightly different trend.

Increased salinity in soybean plants is generally known to reduce plant height, total biomass, yield and leaves quickly experience premature loss (senescence). However, some varieties showed more plant height at higher salinity level and, therefore, the effect of salinity on increasing plant height still requires further research to determine the physiological factors that regulate it. This result implies that evaluating plants tolerance to salinity based only on their growth parameters observed during vegetative stage is not enough, and, therefore, further assessment based on yield parameters is required.

Increased number of filled pods at higher salinity levels was observed in the study as well. This is an interesting and prospective finding for breeding high yielding varieties suitable for saline fields although the physiological mechanisms remain unclear in this study. Number of filled pods is the yield component that describes the tolerance response of varieties to salinity in terms of the ability of plants to maintain the function of leaves as plant photosynthesis organ. Varieties that are sensitive to salinity might experience more leaves loss that causes plant photosynthesis cannot run optimally.

The seed weight, which is generally expressed as 100-seed weight, is one of the most important yield components in soybean that also indicates seed size. Several studies have demonstrated a positive association between seed weight/size and seed yield, as well as seed germination and vigor [13]. The soybean varieties developed in the tropical and subtropical countries, such as India and Indonesia, tend to have a small seed size compared with varieties from the temperate regions, such as USA, China, and Japan. In addition, seed size is also an important factor for soybean end-use. Although a small seed size is preferred for natto (fermented soybean) and soy sprouts, a large seed size is preferred for vegetable soybean and tofu. Therefore, depending on end-use or location of growth, different soybean varieties with different seed sizes have been established. The small-to-very-small sized seeds of all varieties observed in this study was suspected because of salinity stress.

Based on the performance of the yields, Dena 1 and Lokon are considered potential to be candidates for superior parents in salinity tolerant soybean breeding program. And although there were some varieties (Muria and Detam 3) showed increase in yield productivity along with the increase of salinity level, but because their yields were exceptionally low so they could not compete with Lokon and Dena 1. The phenomenon of increasing yield along with increasing salinity levels needs to be further studied to find out the unique plant tolerance mechanism that might be a new superior character of salinity tolerant soybean germplasms.

All the varieties tested was assessed based on their respected tolerance level to salinity using Stress Tolerance Index (STI) and the results showed that nineteen of them were sensitive to salinity, fifteen were moderately tolerant, and only seven were tolerant. Among those tolerant ones, Dena 1 and Lokon were able to yield >1.5 t ha⁻¹ at higher salinity level. These varieties were potential to be used as parental source of salinity tolerance genes for further soybean breeding towards saline-prone area.

The results of this study reflected that sensitive varieties allocate photosynthetic energy to maintain survival by reducing energy allocation for pod and seed formation. In tolerant varieties, more photosynthetic energy allocation is allocated to support the achievement of high yields by reducing energy allocation for high growth. In this regard, the tolerance assessment for salinity stress is more appropriate using yield and its components as main parameters.

4. Conclusions

Evaluated soybean varieties performed various responses to different salinity levels, both in terms of growth and yield parameters. In general, lesser results were observed for most parameters at higher salinity level. Based on the value of STI, 7 varieties were tolerant to salinity but only 2 among them showed yield productivity of >1.5 t ha⁻¹, i.e., Dena 1 and Lokon. Both varieties are very potential to be used as high-yielding parents for salinity tolerant soybean breeding programs. Facing climate change
which has an impact on sea level rise and salinity, the production of tolerant genotypes offers the opportunity to reduce the production costs of saline soybean cultivation.

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