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Revised article No 44472/JAC/202

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joko priyono <joko_priyono@unram.ac.id> Sen, 13 I
kepada Editor

Dear Editor JAC
Please find the revised article No 44472/JAC/2023 attache
files). To accommodate reviewers' comments/notes, I re-wr
highlight the corrected parts. In addition, I also send my co
reviewers' notes.
I hope the revised version meets the publication standard o
further processing.
Thank you.

Best regards,
Joko Priyono

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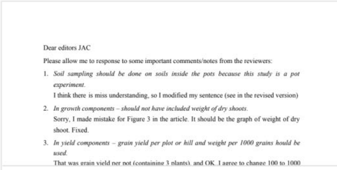

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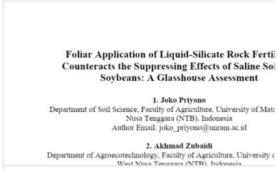

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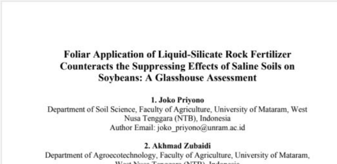

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Paper ID: 44472-JAC-2023
Paper Title: Foliar Application of Liquid-Silicate Rock
Suppressing Effects of Saline Soils on Soybeans: A Gl
Journal: Journal of Agriculture and Crops

Dear Joko Priyono

Foliar Application of Liquid-Silicate Rock Fertilizer Counteracts the Suppressing Effects of Saline Soils on Soybeans: A Glasshouse Assessment

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Abstract: Developing an alternative method for productive farming on saline soils is necessary because remediating the soils is not feasible on-farm. A foliar application of liquid-silicate rock fertilizer (LSRF) was proposed in response to this need, and its effectiveness was evaluated in a greenhouse. The specific aim of the research was to identify the effects of LSRF on the growth and yield components of soybeans grown on salinized soils. The experiment employed a split plot in a completely randomized design, with the main plot consisting of soil salinity levels (EC), i.e., 0.5, 1.5, and 2.5 dS. m^{-1} and the sub-plot was the concentration of applied LSRF, i.e., 0, 1, 2, and 3 %, in triplicates. Results reveal an increase in soil EC to 2.5 dS. m^{-1} slowed down the growth rate and reduced the yield of soybeans by about 20 %. In contrast, applying LSRF at concentrations ranging from 1 to 3% improved soybean growth and yield components while reducing the severity of soil salinity's effects on the plant. Foliar application of LSRF could be an effective method of reducing the stresses caused by saline environments in soybeans.

Keywords: foliar application, saline soils, silicate rock fertilizer, soybeans

1. Introduction

Salty soils and salinization are becoming a global problem threatening crop production sustainability in many countries (FAO-UN, 2021). The causes of soil salinization are locally or regionally specific. In Indonesia, for example, salinization occurs mainly due to the intrusion of seawater into agricultural land. During the wet season, salty water exists in deep soil profiles, while in the dry season, the high evaporation rate moves the saline soil solution to the rooting zone. This natural process results in a seasonal change in soil salinity on most agricultural land near coastal areas in Indonesia.

A high salt (NaCl) concentration in saline soils causes poor soil aeration and an unbalanced supply of nutrients, suppressing plant growth and yield (Rengasamy, 2006; Shin et al., 2016). The standard method recommended by most agricultural experts to neutralize saline soils is soil remediation using gypsum (Ali and Kohlown, 2001), organic matter (Diacono and Montemurro, 2015), or a combination of both and other amendments (Lakhdar et al., 2009; Zaka et al., 2018). In addition, leaching the soil with fresh water was needed to remove the released NaCl (Roy and Chowdury, 2020). Nevertheless, implementing remediation methods on farms is costly and not applicable to small farmers. Thus, it is a challenge for researchers to find more straightforward and low-cost methods to overcome the problems of salt-affected soils for productive farming.

Instead of correcting salt-affected soils, which most farmers do not use, it was proposed to take a more direct approach to feeding nutrients directly to plants. Furthermore, saline soils are a poor source of plant nutrients. Soil salinity is unlikely to have a significant impact on plant growth and yield if the plant acquires complete nutrients, including silicate (Si). Besides that, applying Si was reported to reduce the negative effects of sodium chloride (NaCl) on plant growth and yield (Ali et al., 2012; Ibrahim et al., 2016; Abdelaal et al., 200). The proposed approach was also motivated by the fact that foliar fertilization was an effective method for correcting nutrient imbalances in soils with high salt constituents (Firtz, 1978; Fageria et al., 2009; Fermândez and Brown, 2013). It is entirely possible that plants grown on salt-affected soils will flourish and yield optimally if they receive complete essential nutrients and functional Si from foliar fertilizer

The current study aimed to assess the efficacy of the proposed farming method on salt-affected soils by using soybean as a test plant. The used fertilizer was a liquid-silicate rock fertilizer (LSRF) containing all essential nutrients and Si. The study's specific goal was to determine the effects of foliar LSRF application on the growth and yield of soybeans grown in salinized soils.

2. Material and Method

2.1 Growth Medium and Fertilizer

The growth medium for soybean used in this research was the 20 cm top of sandy loam soil classified as Hapludept from Sekotong, Lombok Island, Indonesia. The soil sample was air-dried, lightly crushed, and screened to pass a 2-mm stainless steel sieve. The soil was nearly neutral (pH_{H2O} 6.4), containing 2.2 % total C-organic, 0.01 % total N, and 4.2 mg. kg^{-1} of Bray II-extractable P. The cation exchange capacity of the soil was 6.6 cmol. kg^{-1} and exchangeable Na, K, Ca, and Mg were respectively 0.2, 1.8, 2.4, and 0.4 cmol. kg^{-1}.

The soil sample was salinized with seawater to reach EC values of 0.5, 1.5, and 2.5 dS. m^{-1}. Before salinizing the soil, a standard curve for soil EC = f (% seawater applied to the soil sample) was prepared. Plastic cups (10 units) were filled with 100 g of the soil sample and saturated with 40 mL water containing 0.1 – 1.0 % seawater. Following a week of equilibration, the soil EC was measured, and the equation of EC (dS. m^{-1}) = 0.095 + 22.59 (% added seawater) was generated. The quantity of seawater added to 10 kg of soil per pot was calculated using the equation. The seawater was mixed with deionized water to 2 L and poured into the soil. After equilibration for a week, the growth medium's salinity level (EC) was measured, and the results were 0.53, 1.52, and 1.46 dS. m^{-1} on average.

Foliar fertilizer - LSRF is a liquid fertilizer made mainly from silicate (basaltic) rocks trademarked as Orrin (produced by PT. JIA Agro Indonesia, West Lombok, Indonesia). Based on its description, Orrin or LSRF contains 4.04 % N, 3.23 % P_2O_5, 3.36 % K_2O, 0.32 % Ca, 0.40 % Mg, 0.12 % S, and 40 mg. L^{-1} Fe, 122 mg. L^{-1} Mn, 260 mg. L^{-1} Zn, 10 mg. L^{-1} Cu, 0.1 mg. L^{-1} Co, 3 mg. L^{-1} B, 1.2 mg. L^{-1}, and 6.4 % Si. The LSRF was first diluted with deionized water to reach the right concentration for treatment before application.

2.2 Experimental Setting

The experiment was carried out in a glasshouse using a split plot arranged in a completely randomized design. The main plot was the salinity level of the growth medium, i.e., 0.5, 1.5, and 2.5 dS. m^{-1}, and the sub-plot was the concentration of LSRF, i.e., 0, 1, 2, and 3 %, in triplicate.

Three soybean seeds (*Willis var*.) were sown directly into the growth medium at about 1 cm depth. Soil moisture in the pots was maintained at about field capacity (20 %) up to 90 days after sowing (DAS). A base fertilizer was superphosphate (18 % P_2O_5), applied to all plants at a rate of 0.3 g. pot^{-1}. The LSRF was sprayed evenly onto the plant leaves four times using a hand sprayer at an interval of 10 days, starting at 7 DAS. The LSRF was applied three times until the plant started to flower. Harvesting was done at 120 DAS.

2.3 Parameters and Statistical Analyses

The assessed growth components were plant heights at 21, 35, and 49 DAS, the total number of leaves, and the weight of the dry shoot. The yield components included the number of filled pods, the weight of total grains, and the weight of 1000 grains. Analyses of variance were carried out to identify the effects of the treatments on the observed parameters. The most suitable regression model, i.e., the power equation, was used to describe the patterns of LSRF affecting each observed parameter at different soil EC. The general regression model was $Y = Y_o + bX^n$, in which Y was the predicted value of an observed parameter, Y_o was the value of Y when X = 0, b was the experimental constant, X was the concentration of applied LSRF (%), and n was the order or skewness of the regression line.

3. Results and Discussion

3.1 Growth Components

The results of analyses of the variant show that soil EC, the concentration of applied LSRF, and the interaction of both factors significantly ($p < 0.05$) affected all observed growth components. The relationships between the treatments versus the growth components are presented in Figures 1 – 3.

Effects of treatments on plant height

Figure 1 demonstrates the increase in soil EC from 0.5 to 2.5 dS. m^{-1} holds up the growth of soybeans at all growing stages (21, 35, and 49 DAS); the older the plant, the more severe the effect of soil EC on plant height. On the other hand, foliar application of LSRF stimulates elongation in soybeans. Also, the interaction of both treatments significantly affected plant height, and the higher the soil EC, the stronger the positive impact of LSRF on plant height. At 49 DAS, for example, when no LSRF was applied, the soil EC increased from 0.5 to 2.5 dS. m^{-1} caused 27 cm (36 %) lower plant height. However, when LSRF was applied at a concentration of 3 %, the increase of soil EC reduced the plant height by only about 7 cm (8 %). In other words, the application of LSRF at a concentration of 1 – 3 % reverses the harmful effects of soil salinity on the elongation process of the plant.

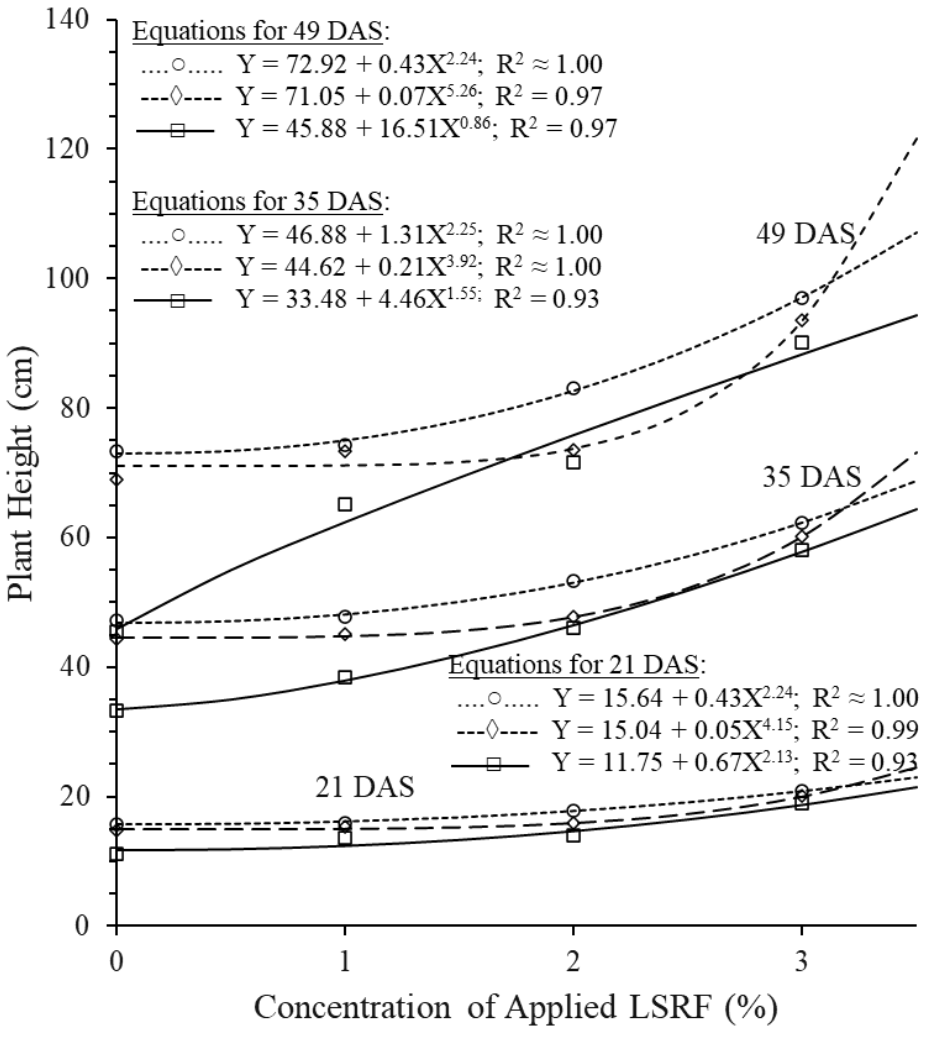

Figure 1. The relationships between plant height (Y, cm) at 21, 35, and 49 DAS (days after sowing) and concentration (X, %) of applied LSRF (liquid-silicate rock fertilizer) for the soil salinities of 0.5 dS. m^{-1} (…○…), 1.5 dS. m^{-1} (---◊---), and 2.5 dS. m^{-1} (—□—).

Effects of treatments on the number of plant leaves

For another growth component – the number of plant leaves as shown in Figure 2, the increase in soil EC from 0.5 to 2.5 dS. m^{-1} reduced the number of plant leaves by about 33 % (from 55 down to 37). In contrast, the increased concentration of applied LSRF to 3 % nearly doubled the number of soybean leaves. In addition, the interaction between both treatments significantly affected the number of plant leaves, but this effect showed an inconsistent pattern. In the study, the interaction effect appeared to be that for the low concentration (1%) of applied LSRF, the intensity effect of LSRF application was intensified by soil EC, but reversed for higher soil EC. It confirms that the application of LSRF at low concentrations (< 1 %) strongly counteracted the adverse effects of soil EC on the growth of soybeans, but that was slightly weakened by higher concentrations (> 3 %) of the LSRF.

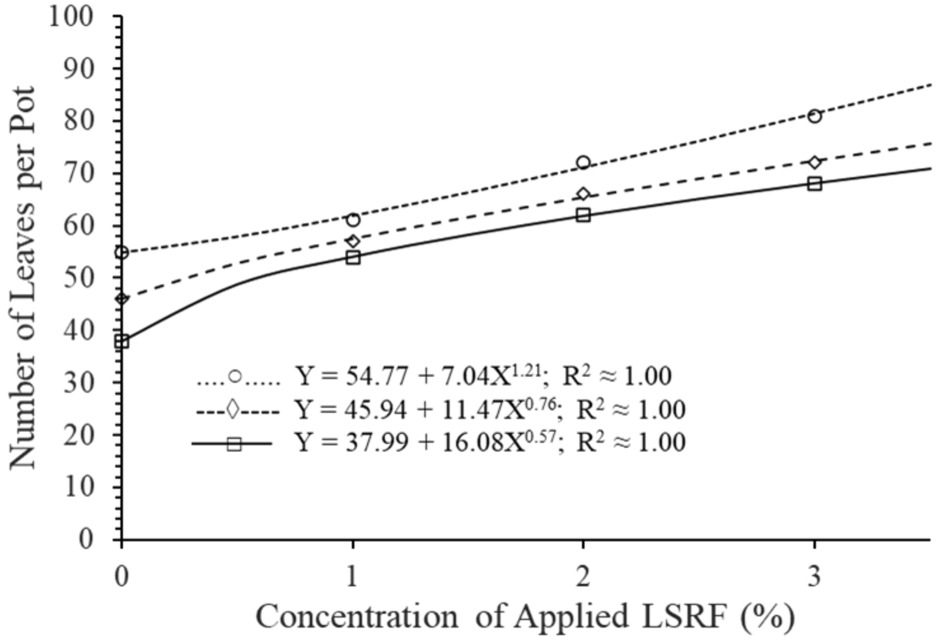

Figure 2. The relationships between number of plant leaves per pot of three plants (Y) and concentration (X, %) of applied LSRF (liquid-silicate rock fertilizer) for soil salinities of 0.5 dS. m^{-1} (…○…), 1.5 dS. m^{-1} (---◊---), and 2.5 dS. m^{-1} (—□—).

Effects of treatments on the weight of dry shoot

Figure 3 demonstrates the pattern of relationships between the treatments and the weight of the dry shoot. The graph indicates that an increase in soil EC lowers the weight of soybeans' dry shoots. Conversely, applying LSRF improved the weight of the plant's dry shoots, and this positive effect became more pronounced with a higher soil EC value. This interaction effect confirms that the foliar application of LSRF diminished the suppressive effects of soil EC on another growth component (weight of dry shoot) of soybeans.

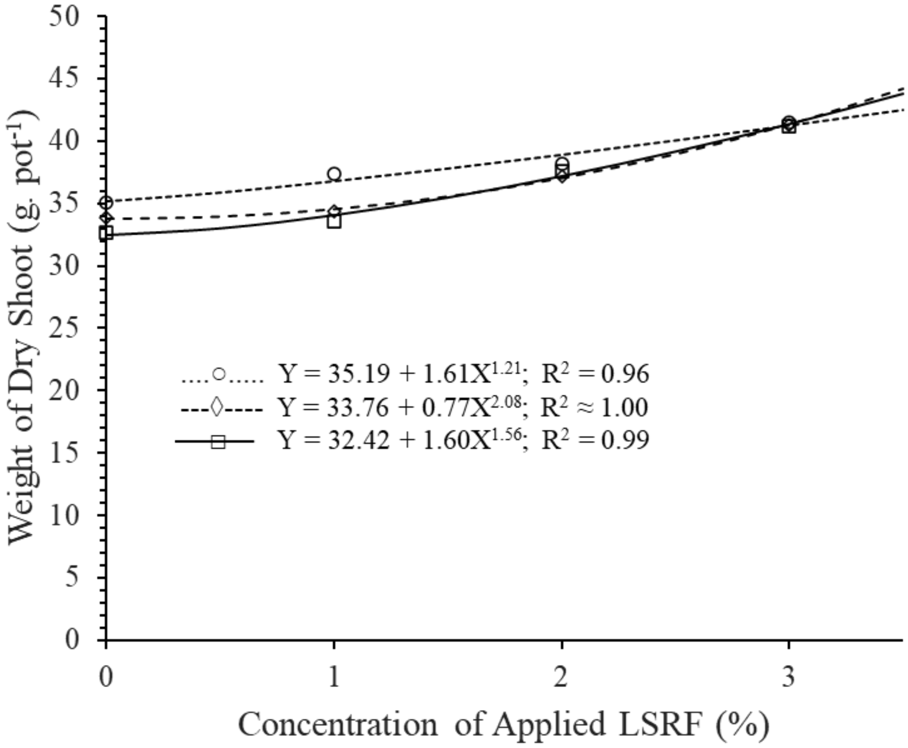

Figure 3. The relationships between the weight of dry shoot (Y, g. pot^{-1}) and concentration (X, in %) of applied LSRF (liquid-silicate rock fertilizer) for soil salinities of 0.5 (…○…), 1.5 (---◊---), and 2.5 (—⊟—) dS. m^{-1}.

3.2 Yield Components

Statistically, the soil salinity (EC) level, the concentration of applied LSRF, and the interaction of both significantly ($p < 0.05$) affected the number of filled pods and the weights of total and 1000 grains of soybeans. The relationships between the treatments and the yield parameters are illustrated in Figures 4 – 6. In general, the trends of treatments affecting the yield components are like those for the growth components.

Effects of treatments on the number of filled pods

Figure 4 shows the increase in soil EC from 0.5 to 2.5 dS. m^{-1} lowered the number of filled pods by about 34 %. On the other hand, the increased concentration of applied LSRF up to 3 % sharply increased the number of filled pods by 40 to 90 %. Furthermore, these beneficial effects of LSRF application more intensely decreased the negative effects of the high-soil EC on the number of pods, so that with the application of LSRF 3 %, there was no significant difference between the number of soybean pods with the soil EC of 0.5 and 2.5 dS. m^{-1}.

Effects of treatments on the weight of total grains

Figure 5 illustrates the trends of the effects of treatments on the weight of total grains, which are comparable with those for the number of filled pods (Figure 4). The increase in soil salinity up to 2.5 dS. m^{-1} reduces about 20 % of plant yield. Conversely, the foliar application of LSRF up to a concentration of 3 % increased yield by about 43 % (i.e., from 35 to 50 g. pot^{-1}). At the same time, LSRF minimizes the reduction in plant yield caused by soil salinity.

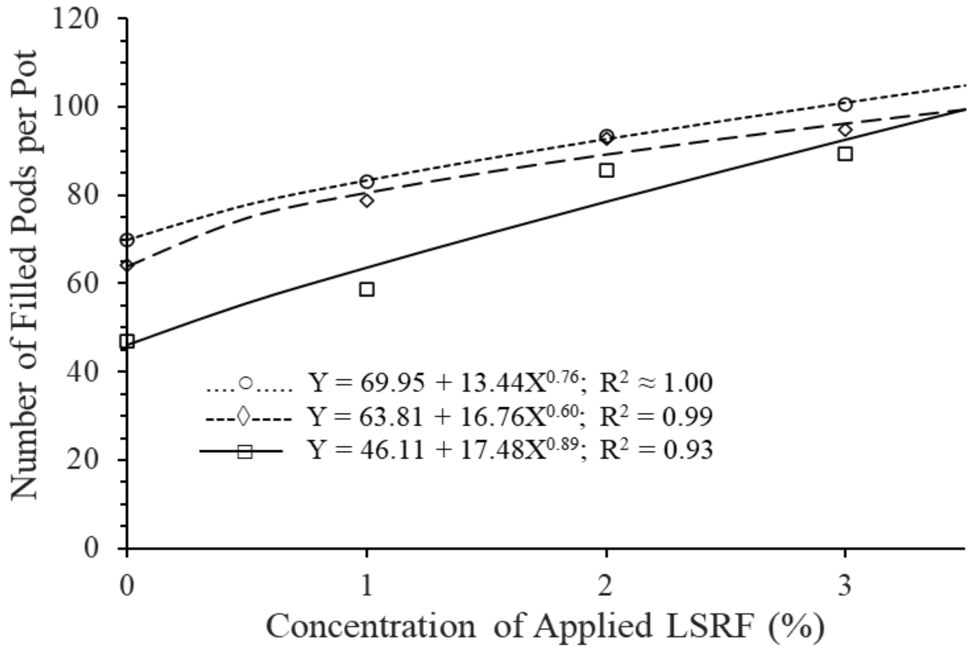

Figure 4. The relationships between the number of filled pods (Y) and concentration (X, in %) of applied LSRF (liquid-silicate rock fertilizer) for soil salinities of 0.5 (…○…), 1.5 (---◊---), and 2.5 (—⊟—) dS. m^{-1}.

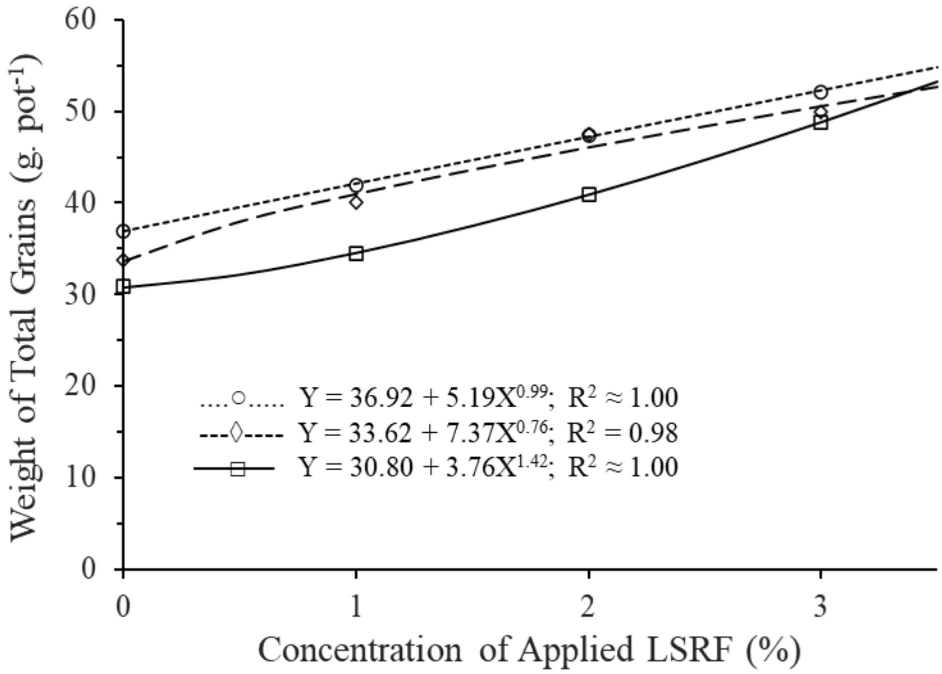

Figure 5. The relationships between the weight of total grains (Y, g. pot^{-1}) and concentration (X, %) of applied LSRF (liquid-silicate rock fertilizer) for soil salinities of 0.5 (…○…), 1.5 (---◊---), and 2.5 (—⊟—) dS. m^{-1}.

Effects of treatments on the weight of 1000 grains

As shown in Figure 6, soil EC increased from 0.5 to 2.5 dS. m^{-1} reduced the weight of 1000 grains by about 5 % (from 146 down to 139 g). In contrast, the application of LSRF, especially at concentrations of > 2 %, sharply optimized the quality of soybean grains while minimizing the suppressive effects of soil EC. This result is another proof that the application of LSRF nullifies the suppressing effects of saline soils on the yield of soybeans.

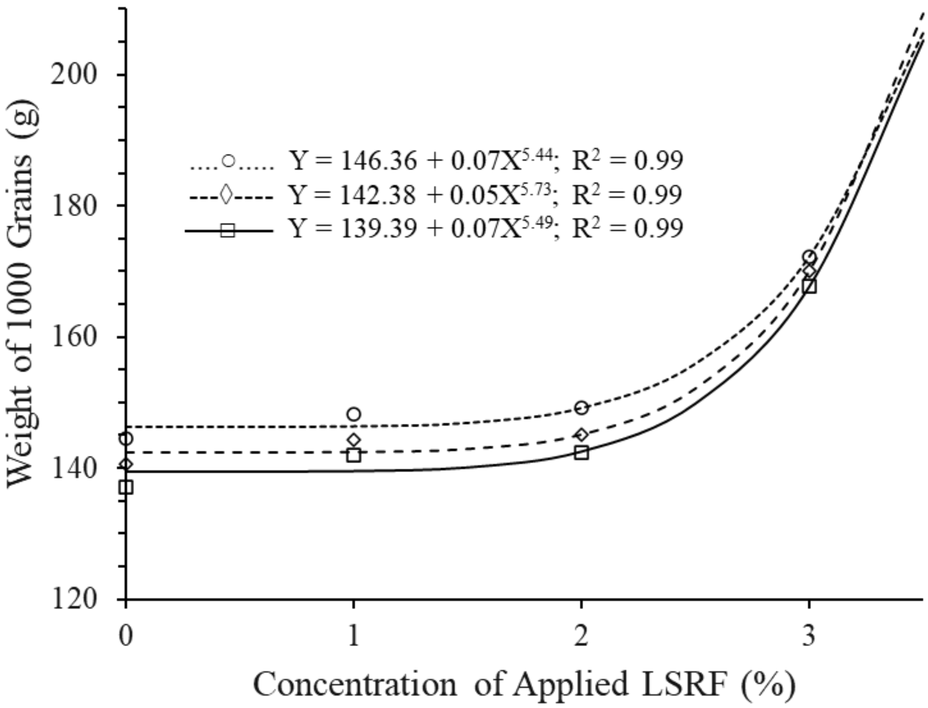

Figure 6. The relationships between the weight of 1000 grains (Y, g) and concentration (X, %) of applied LSRF (liquid-silicate rock fertilizer) on soil salinities of 0.5 (…○…), 1.5 (---◊---), and 2.5 (—⊟—) dS. m^{-1}.

4. Discussion

The current study's findings show similar trends in the response of soybeans, as represented by growth and yield components, to treatments of soil salinity (EC) level and concentration of applied LSRF. Increased salinity suppresses plant growth, whereas LSRF applications stimulate it. Simultaneously, the positive effects of LSRF application mitigate the negative effects of soil EC. It is interesting to note that the latter finding is relevant to efforts to find the best agricultural methods for saline soils without remediation.

The effect of saline soil on the growth and yield of various plants is well known throughout the world. This could be due to osmotic tension, nutritional imbalance, or a combination of factors inhibiting plant growth and yield. Many researches including Bustingorri et al. (2011), Hashi et al. (2015), and Hang and Mai (2016) have all reported specific effects on soybean yield and growth. The results of current study are consistent with the negative effects of salinized soils on soybean growth and yield.

Liquid-silicate rock fertilizer (LSRF) used in this research is a local product containing all essential nutrients and Si. So far, there is no published report about the effectiveness of LSRF for farming on saline soils. However, for farming on non-saline soils, foliar applications of LSRF were reported to improve the resistance of cocoa to pest attacks and produce higher quantities and quality of cocoa beans (Priyono et al., 2020a) as well as sugar cane and sugar concentration (Priyono et al., 2020b). LSRF application may also improve nutrient balance by virtue of the beneficial function of Si, which element is present in LSRF.

The significant effects of the interaction of soil salinity with the concentration of applied LSRF in this present research describe that the higher the soil salinity (EC), the more intense the positive effects of LSRF on the growth and yield components of soybeans. The foliar application of LSRF counteracts the negative effects of soil salinity on soybean growth and yield. Since the LSRF contains Si, this study's finding may be comparable to the results of Ali et al. (2012), Abbas et al. (2017), Alzahrani et al. (2018), and Abdelaal et al. (2020) who reported that the supply of Si alleviates salt stress and improves the growth or yield of plants.

Synthesizing the main results of this research, the direct supply of all essential nutrients and Si improved the plant's growth, yield, and adaptability of the plant (soybeans) to salty environments. Based on these results, the foliar application of LSRF may be a favorable solution for productive farming on salt-affected soils. Further researches, however, are necessary to be carried out in field conditions for various types of crops and soil salinity levels.

5. Conclusion

Foliar applications of LSRF containing all essential nutrients and Si clearly improved soybean performance on salinized soils up to 2.5 dS. m^{-1}, and counteracted the suppressive effects of soil salinity on plant growth and yield. Foliar application of LSRF may be promoted as an appropriate solution for productive farming on salt-affected soils.

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Balas Balas ke semua

Dear editors JAC

Please allow me to response to some important comments/notes from the reviewers:

1. *Soil sampling should be done on soils inside the pots because this study is a pot experiment*.

   I think there is miss understanding, so I modified my sentence (see in the revised version)

2. *In growth components – should not have included weight of dry shoots*.

   Sorry, I made mistake for Figure 3 in the article. It should be the graph of weight of dry shoot. Fixed.

3. *In yield components – grain yield per plot or hill and weight per 1000 grains hould be used.*

   That was grain yield per pot (containing 3 plants), and OK..I agree to change 100 to 1000 grains. Actually, there is no valid reason of using 100 or 1000 grains.

4. *No analysis was mentioned to test significant differences between treatment means*.

   In my opinion, there is no point to compare between parameter means, and data should be presented in table form or bar graph. I prefer to use regression analyses describing the characteristics of the data (parameters vs treatments); and applying this method is easier to explain validly the trends for the effects of single factor and interaction of both factors for each assessed parameter.

   In my fist article, I used polynomial regression model. But, I realize that is not the best expression for the present data. So, I change my mind to use power equation model (see the explanation in the revised file, section 2.3).

5. Thanks for the other comments/notes. Those were due to my careless in writing the articles. I re-write my article 44472 jac.

Thank you.

Joko Priyono.

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Foliar Application of Liquid-Silicate Rock Fertilizer Counteracts the Suppressing Effects of Saline Soils on Soybeans: A Glasshouse Assessment

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Abstract

Developing an alternative method for productive farming on saline soils is necessary because remediating the soils is not feasible on-farm. A foliar application of liquid-silicate rock fertilizer (LSRF) was proposed in response to this need, and its effectiveness was evaluated in a greenhouse. The specific aim of the research was to identify the effects of LSRF on the growth and yield components of soybeans grown on salinized soils. The experiment employed a split plot in a completely randomized design, with the main plot consisting of soil salinity levels (EC), i.e., 0.5, 1.5, and 2.5 dS. m^{-1} and the sub-plot was the concentration of applied LSRF, i.e., 0, 1, 2, and 3 %, in triplicates. Results reveal an increase in soil EC to 2.5 dS. m^{-1} slowed down the growth rate and reduced the yield of soybeans by about 20 %. In contrast, applying LSRF at concentrations ranging from 1 to 3% improved soybean growth and yield components while reducing the severity of soil salinity's effects on the plant. Foliar application of LSRF could be an effective method of reducing the stresses caused by saline environments in soybeans.

Keywords: Foliar application; Saline soils; Silicate rock fertilizer; Soybeans.

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1. Introduction

Salty soils and salinization are becoming a global problem threatening crop production sustainability in many countries [1]. The causes of soil salinization are locally or regionally specific. In Indonesia, for example, salinization occurs mainly due to the intrusion of seawater into agricultural land. During the wet season, salty water exists in deep soil profiles, while in the dry season, the high evaporation rate moves the saline soil solution to the rooting zone. This natural process results in a seasonal change in soil salinity on most agricultural land near coastal areas in Indonesia.

A high salt (NaCl) concentration in saline soils causes poor soil aeration and an unbalanced supply of nutrients, suppressing plant growth and yield [2, 3]. The standard method recommended by most agricultural experts to neutralize saline soils is soil remediation using gypsum [4], organic matter [5], or a combination of both and other amendments [6, 7]. In addition, leaching the soil with fresh water was needed to remove the released NaCl [8]. Nevertheless, implementing remediation methods on farms is costly and not applicable to small farmers. Thus, it is a challenge for researchers to find more straightforward and low-cost methods to overcome the problems of salt-affected soils for productive farming.

Instead of correcting salt-affected soils, which most farmers do not use, it was proposed to take a more direct approach to feeding nutrients directly to plants. Furthermore, saline soils are a poor source of plant nutrients. Soil salinity is unlikely to have a significant impact on plant growth and yield if the plant acquires complete nutrients, including silicate (Si). Besides that, applying Si was reported to reduce the negative effects of sodium chloride (NaCl) on plant growth and yield [9-11]. The proposed approach was also motivated by the fact that foliar fertilization was an effective method for correcting nutrient imbalances in soils with high salt constituents [12-14]. It is entirely possible that plants grown on salt-affected soils will flourish and yield optimally if they receive complete essential nutrients and functional Si from foliar fertilizer

The current study aimed to assess the efficacy of the proposed farming method on salt-affected soils by using soybean as a test plant. The used fertilizer was a liquid-silicate rock fertilizer (LSRF) containing all essential nutrients and Si. The study's specific goal was to determine the effects of foliar LSRF application on the growth and yield of soybeans grown in salinized soils.

2. Material and Method

2.1. Growth Medium and Fertilizer

The growth medium for soybean used in this research was the 20 cm top of sandy loam soil classified as Hapludept from Sekotong, Lombok Island, Indonesia. The soil sample was air-dried, lightly crushed, and screened to pass a 2-mm stainless steel sieve. The soil was nearly neutral (pH_{H2O} 6.4), containing 2.2 % total C-organic, 0.01 % total N, and 4.2 mg. kg^{-1} of Bray II-extractable P. The cation exchange capacity of the soil was 6.6 cmol. kg^{-1} and exchangeable Na, K, Ca, and Mg were respectively 0.2, 1.8, 2.4, and 0.4 cmol. kg^{-1}.

The soil sample was salinized with seawater to reach EC values of 0.5, 1.5, and 2.5 dS. m^{-1}. Before salinizing the soil, a standard curve for soil EC = f (% seawater applied to the soil sample) was prepared. Plastic cups (10 units) were filled with 100 g of the soil sample and saturated with 40 mL water containing 0.1 – 1.0 % seawater. Following a week of equilibration, the soil EC was measured, and the equation of EC (dS. m^{-1}) = 0.095 + 22.59 (% added seawater) was generated. The quantity of seawater added to 10 kg of soil per pot was calculated using the equation. The seawater was mixed with deionized water to 2 L and poured into the soil. After equilibration for a week, the growth medium's salinity level (EC) was measured, and the results were 0.53, 1.52, and 1.46 dS. m^{-1} on average.

Foliar fertilizer - LSRF is a liquid fertilizer made mainly from silicate (basaltic) rocks trademarked as Orrin (produced by PT. JIA Agro Indonesia, West Lombok, Indonesia). Based on its description, Orrin or LSRF contains 4.04 % N, 3.23 % P_2O_5, 3.36 % K_2O, 0.32 % Ca, 0.40 % Mg, 0.12 % S, and 40 mg. L^{-1} Fe, 122 mg. L^{-1} Mn, 260 mg. L^{-1} Zn, 10 mg. L^{-1} Cu, 0.1 mg. L^{-1} Co, 3 mg. L^{-1} B, 1.2 mg. L^{-1}, and 6.4 % Si. The LSRF was first diluted with deionized water to reach the right concentration for treatment before application.

2.2. Experimental Setting

The experiment was carried out in a glasshouse using a split plot arranged in a completely randomized design. The main plot was the salinity level of the growth medium, i.e., 0.5, 1.5, and 2.5 dS. m^{-1}, and the sub-plot was the concentration of LSRF, i.e., 0, 1, 2, and 3 %, in triplicate.

Three soybean seeds (*Willis var*.) were sown directly into the growth medium at about 1 cm depth. Soil moisture in the pots was maintained at about field capacity (20 %) up to 90 days after sowing (DAS). A base fertilizer was superphosphate (18 % P_2O_5), applied to all plants at a rate of 0.3 g. pot^{-1}. The LSRF was sprayed evenly onto the plant leaves four times using a hand sprayer at an interval of 10 days, starting at 7 DAS. The LSRF was applied three times until the plant started to flower. Harvesting was done at 120 DAS.

2.3. Parameters and Statistical Analyses

The assessed growth components were plant heights at 21, 35, and 49 DAS, the total number of leaves, and the weight of the dry shoot. The yield components included the number of filled pods, the weight of total grains, and the weight of 1000 grains. Analyses of variance were carried out to identify the effects of the treatments on the observed parameters. The most suitable regression model, i.e., the power equation, was used to describe the patterns of LSRF affecting each observed parameter at different soil EC. The general regression model was $Y = Y_o + bX^n$, in which Y was the predicted value of an observed parameter, Y_o was the value of Y when X = 0, b was the experimental constant, X was the concentration of applied LSRF (%), and n was the order or skewness of the regression line.

3. Results and Discussion

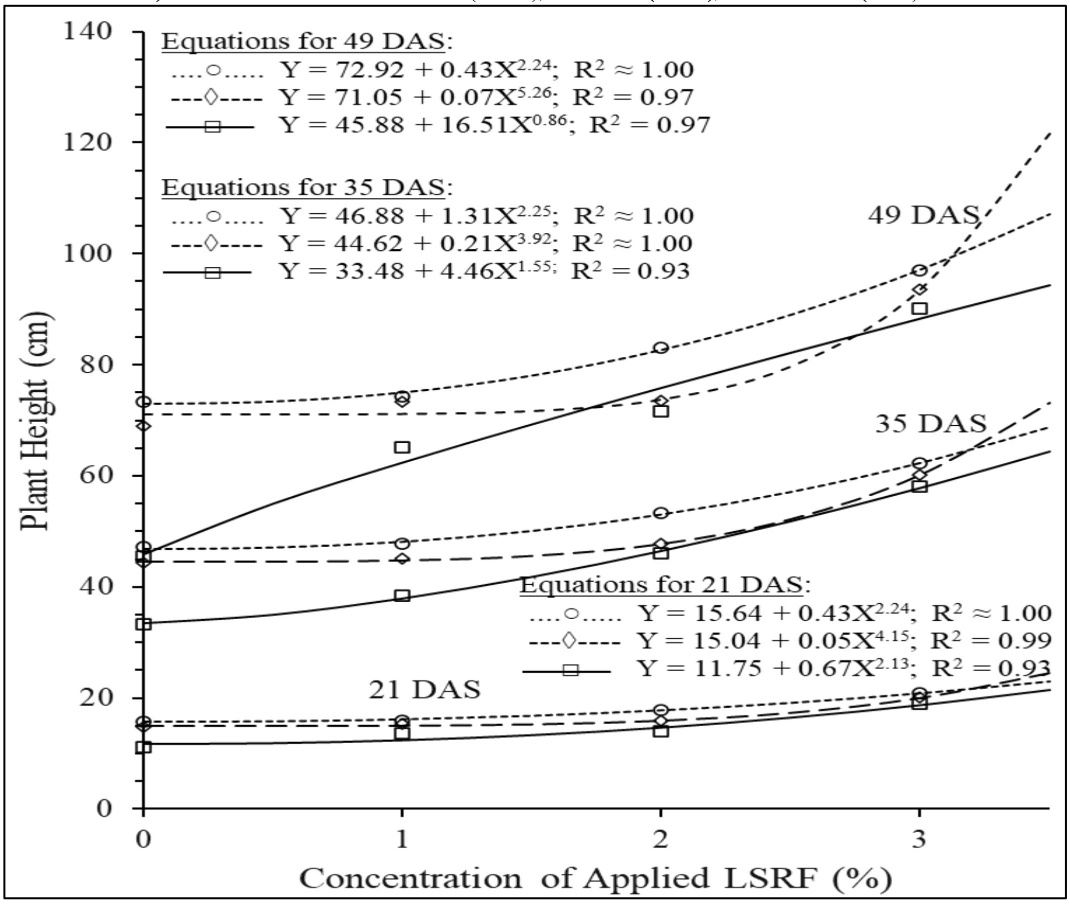
3.1. Growth Components

The results of analyses of the variant show that soil EC, the concentration of applied LSRF, and the interaction of both factors significantly ($p < 0.05$) affected all observed growth components. The relationships between the treatments versus the growth components are presented in Figures 1, 2, 3.

3.1.1. Effects of Treatments on Plant Height

Figures 1 demonstrates the increase in soil EC from 0.5 to 2.5 dS. m^{-1} holds up the growth of soybeans at all growing stages (21, 35, and 49 DAS); the older the plant, the more severe the effect of soil EC on plant height. On the other hand, foliar application of LSRF stimulates elongation in soybeans. Also, the interaction of both treatments significantly affected plant height, and the higher the soil EC, the stronger the positive impact of LSRF on plant height. At 49 DAS, for example, when no LSRF was applied, the soil EC increased from 0.5 to 2.5 dS. m^{-1} caused 27 cm (36 %) lower plant height. However, when LSRF was applied at a concentration of 3 %, the increase of soil EC reduced the plant height by only about 7 cm (8 %). In other words, the application of LSRF at a concentration of 1 – 3 % reverses the harmful effects of soil salinity on the elongation process of the plant.

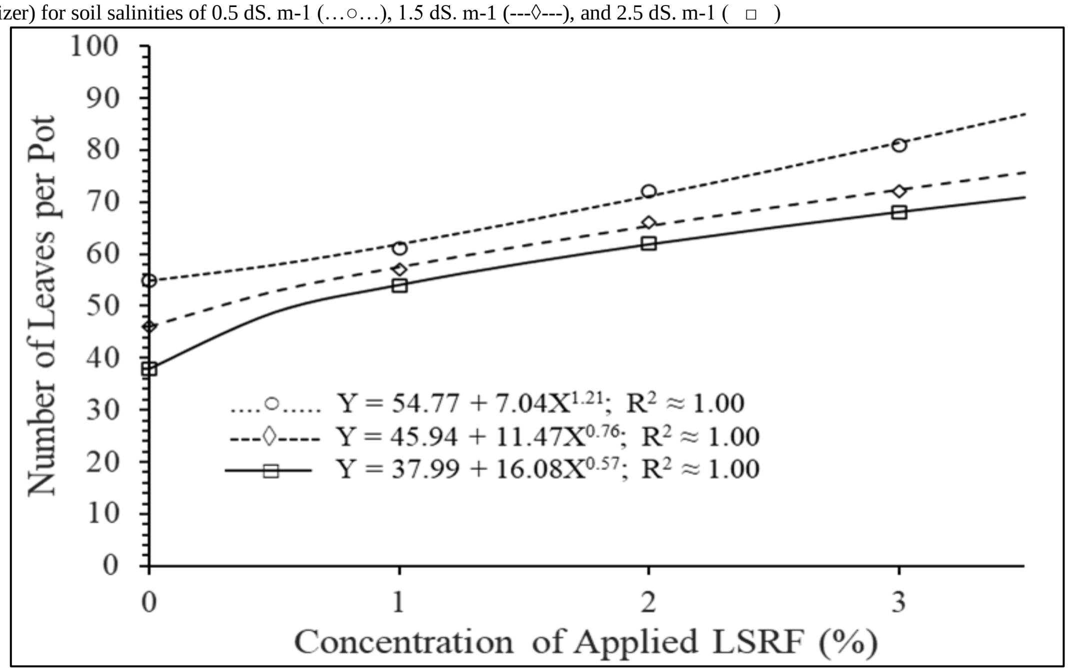
Figure-1. The relationships between plant height (Y, cm) at 21, 35, and 49 DAS (days after sowing) and concentration (X, %) of applied LSRF (liquid-silicate rock fertilizer) for the soil salinities of 0.5 dS. m^{-1} (…○…), 1.5 dS. m^{-1} (---◊---), and 2.5 dS. m^{-1} (□)



3.1.2. Effects of Treatments on the Number of Plant Leaves

For another growth component – the number of plant leaves as shown in Figure 2, the increase in soil EC from 0.5 to 2.5 dS. m^{-1} reduced the number of plant leaves by about 33 % (from 55 down to 37). In contrast, the increased concentration of applied LSRF to 3 % nearly doubled the number of soybean leaves. In addition, the interaction between both treatments significantly affected the number of plant leaves, but this effect showed an inconsistent pattern. In the study, the interaction effect appeared to be that for the low concentration (1%) of applied LSRF, the intensity effect of LSRF application was intensified by soil EC, but reversed for higher soil EC. It confirms that the application of LSRF at low concentrations (< 1 %) strongly counteracted the adverse effects of soil EC on the growth of soybeans, but that was slightly weakened by higher concentrations (> 3 %) of the LSRF.

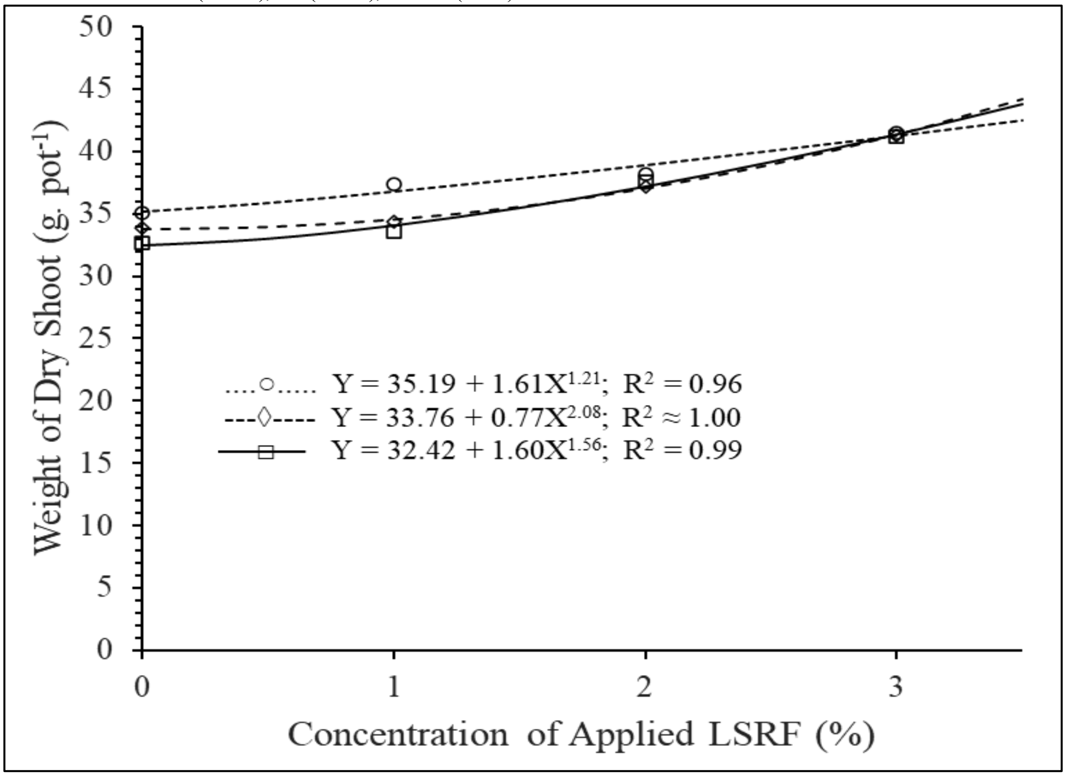
Figure-2. The relationships between number of plant leaves per pot of three plants (Y) and concentration (X, %) of applied LSRF (liquid-silicate rock fertilizer) for soil salinities of 0.5 dS. m-1 (…○…), 1.5 dS. m-1 (---◊---), and 2.5 dS. m-1 (□)



3.1.3. Effects of Treatments on the Weight of Dry Shoot

Figure 3 demonstrates the pattern of relationships between the treatments and the weight of the dry shoot. The graph indicates that an increase in soil EC lowers the weight of soybeans' dry shoots. Conversely, applying LSRF improved the weight of the plant's dry shoots, and this positive effect became more pronounced with a higher soil EC value. This interaction effect confirms that the foliar application of LSRF diminished the suppressive effects of soil EC on another growth component (weight of dry shoot) of soybeans.

Figure-3. The relationships between the weight of dry shoot (Y, g. pot^{-1}) and concentration (X, in %) of applied LSRF (liquid-silicate rock fertilizer) for soil salinities of 0.5 (…○…), 1.5 (---◊---), and 2.5 (□) dS. m^{-1}



3.2. Yield Components

Statistically, the soil salinity (EC) level, the concentration of applied LSRF, and the interaction of both significantly ($p < 0.05$) affected the number of filled pods and the weights of total and 1000 grains of soybeans. The relationships between the treatments and the yield parameters are illustrated in Figures 4, 5, 6. In general, the trends of treatments affecting the yield components are like those for the growth components.

3.2.1. Effects of Treatments on the Number of Filled Pods

Figure 4 shows the increase in soil EC from 0.5 to 2.5 dS. m^{-1} lowered the number of filled pods by about 34 %. On the other hand, the increased concentration of applied LSRF up to 3 % sharply increased the number of filled pods by 40 to 90 %. Furthermore, these beneficial effects of LSRF application more intensely decreased the negative effects of the high-soil EC on the number of pods, so that with the application of LSRF 3 %, there was no significant difference between the number of soybean pods with the soil EC of 0.5 and 2.5 dS. m^{-1}.

3.2.2. Effects of Treatments on the Weight of Total Grains

Figure 5 illustrates the trends of the effects of treatments on the weight of total grains, which are comparable with those for the number of filled pods (Figure 4). The increase in soil salinity up to 2.5 dS. m^{-1} reduces about 20 % of plant yield. Conversely, the foliar application of LSRF up to a concentration of 3 % increased yield by about 43 % (i.e., from 35 to 50 g. pot^{-1}). At the same time, LSRF minimizes the reduction in plant yield caused by soil salinity.

Figure-4. The relationships between the number of filled pods (Y) and concentration (X, in %) of applied LSRF (liquid-silicate rock fertilizer) for soil salinities of 0.5 (…○…), 1.5 (---◊---), and 2.5 (□) dS. m^{-1}

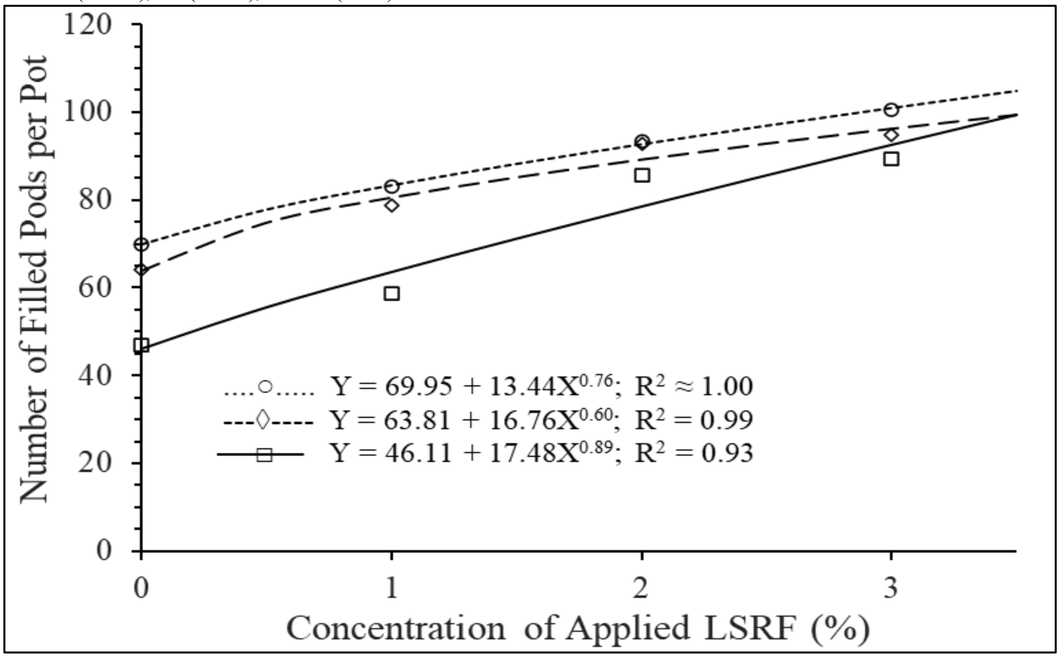
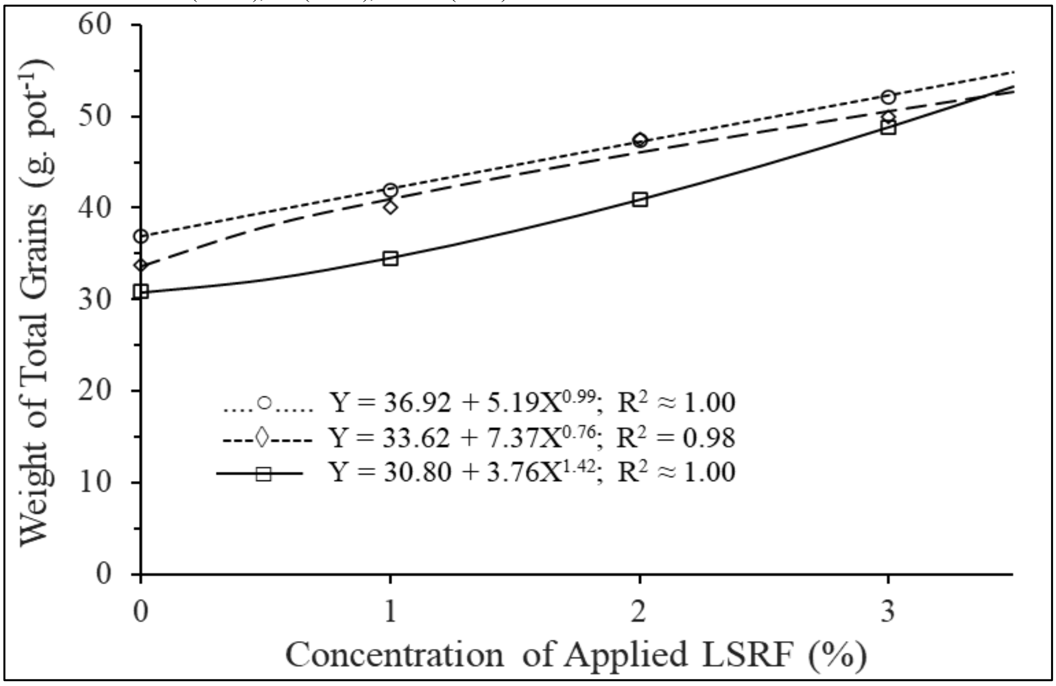


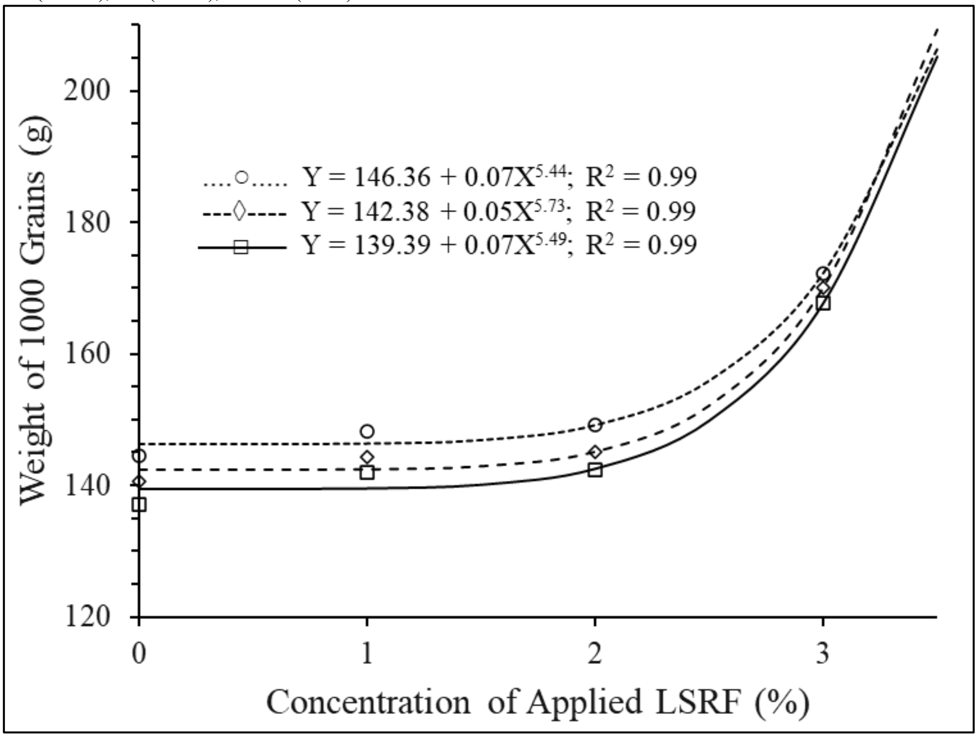
Figure-5. The relationships between the weight of total grains (Y, g. pot^{-1}) and concentration (X, %) of applied LSRF (liquid-silicate rock fertilizer) for soil salinities of 0.5 (…○…), 1.5 (---◊---), and 2.5 (□) dS. m^{-1}



3.2.3. Effects of Treatments on the Weight of 1000 Grains

As shown in Figure 6, soil EC increased from 0.5 to 2.5 dS. m^{-1} reduced the weight of 1000 grains by about 5 % (from 146 down to 139 g). In contrast, the application of LSRF, especially at concentrations of > 2 %, sharply optimized the quality of soybean grains while minimizing the suppressive effects of soil EC. This result is another proof that the application of LSRF nullifies the suppressing effects of saline soils on the yield of soybeans.

Figure-6. The relationships between the weight of 1000 grains (Y, g) and concentration (X, %) of applied LSRF (liquid-silicate rock fertilizer) on soil salinities of 0.5 (…○…), 1.5 (---◊---), and 2.5 (□) dS. m^{-1}



4. Discussion

The current study's findings show similar trends in the response of soybeans, as represented by growth and yield components, to treatments of soil salinity (EC) level and concentration of applied LSRF. Increased salinity suppresses plant growth, whereas LSRF applications stimulate it. Simultaneously, the positive effects of LSRF application mitigate the negative effects of soil EC. It is interesting to note that the latter finding is relevant to efforts to find the best agricultural methods for saline soils without remediation.

The effect of saline soil on the growth and yield of various plants is well known throughout the world. This could be due to osmotic tension, nutritional imbalance, or a combination of factors inhibiting plant growth and yield. Many researches including Bustingorri and Lavado [15], Hashi, *et al.* [16] and Hang. and Mai [17] have all reported specific effects on soybean yield and growth. The results of current study are consistent with the negative effects of salinized soils on soybean growth and yield.

Liquid-silicate rock fertilizer (LSRF) used in this research is a local product containing all essential nutrients and Si. So far, there is no published report about the effectiveness of LSRF for farming on saline soils. However, for farming on non-saline soils, foliar applications of LSRF were reported to improve the resistance of cocoa to pest attacks and produce higher quantities and quality of cocoa beans [18] as well as sugar cane and sugar concentration [19]. LSRF application may also improve nutrient balance by virtue of the beneficial function of Si, which element is present in LSRF.

The significant effects of the interaction of soil salinity with the concentration of applied LSRF in this present research describe that the higher the soil salinity (EC), the more intense the positive effects of LSRF on the growth and yield components of soybeans. The foliar application of LSRF counteracts the negative effects of soil salinity on soybean growth and yield. Since the LSRF contains Si, this study's finding may be comparable to the results of Ali, *et al.* [9], Abbas, *et al.* [20], Alzahrani, *et al.* [21], and Abdelaal, *et al.* [11] who reported that the supply of Si alleviates salt stress and improves the growth or yield of plants.

Synthesizing the main results of this research, the direct supply of all essential nutrients and Si improved the plant's growth, yield, and adaptability of the plant (soybeans) to salty environments. Based on these results, the foliar application of LSRF may be a favorable solution for productive farming on salt-affected soils. Further researches, however, are necessary to be carried out in field conditions for various types of crops and soil salinity levels.

5. Conclusion

Foliar applications of LSRF containing all essential nutrients and Si clearly improved soybean performance on salinized soils up to 2.5 dS. m^{-1}, and counteracted the suppressive effects of soil salinity on plant growth and yield. Foliar application of LSRF may be promoted as an appropriate solution for productive farming on salt-affected soils.

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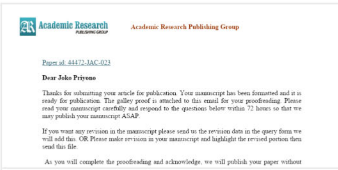

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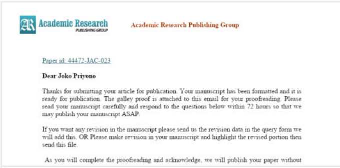

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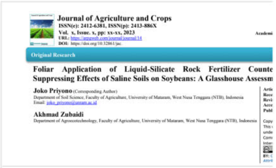

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