Akta Agrosia

Amelioration of Salinity Stressed Soil Using Natural Zeolite for Improving Soil Properties and Chinese Cabbage Agronomic Performances

Tantrie Dhamar Romadhan[1], Marwanto Marwanto[1*], Bambang Gonggo Murcitro[2], Merakati Handajaningsih[1]

[1]Department of Agronomy, Agriculture Faculty, Bengkulu University
[2]Department of Soil Science, Agriculture Faculty, Bengkulu University

ABSTRACT

Salinity stress is the major abiotic stress for crop production. The purpose of this study was to evaluate the effectiveness of zeolite on improving soil properties, the growth, and yield of Chinese cabbage. This pot experiment was conducted from September to November 2020 at the Research and Teaching Field of the Faculty of Agriculture, consisted of 6 treatment levels, i.e. (1) control, (2) soil + 6.9 g NaCl /10 kg soil, (3) soil + 6.9 g Na_2SO_4 /10 kg soil, (4) soil + 3.2 g zeolite /10 kg soil, (5) soil + 6.9 g NaCl /10 kg soil + 3.2 g zeolite /10 kg soil, and (6) soil + 6.9 g Na_2SO_4 /10 kg soil + 3.2 g zeolite /10 kg of soil, and arranged in a completely randomized design with 3 replications. The application of zeolite decreased the EC of salinized soil and increased the soil CEC. NaCl salinity stress reduced plant height (23%), number of leaves (22%), fresh weight of roots (165%), dry weight of roots (170%), stalk length (32%), and plant dry weight (131%), while Na_2SO_4 salinity stress only reduced the number of leaves (23%). The addition of zeolite to salinized NaCl soil increased stalk length (39%), plant fresh weight (172%), leaf fresh weight (174%), plant dry weight (133%), and leaf dry weight (23%), while to salinized Na_2SO_4 soil only increased plant dry weight (90%) and leaf dry weight (177%). The overall results show that the addition of zeolite can effectively ameliorate salinity stress due to NaCl.

INTRODUCTION

Efforts to expand agricultural land are now directed to marginal land, such as saline land because it is the largest marginal land in Indonesia (ICRDALR, 2012) and also because of the limited productive agricultural land due to land conversion. According to data from the ICRDALR, the area of saline land in Indonesia is ± 27.4 million ha consisting of tidal plains and coastal areas, dry land and tidal swamp land. Karolinoerita and Annisa (2020) stated that the area of tidal and coastal plains reached 12,020 million ha or 6.20% of the total land area of Indonesia. This area is spread in almost all parts of Indonesia (including Bengkulu) and

is a landscape that is directly caused by rising sea levels or tidal waves and sea water intrusion which can cause an increase in salt levels (salinity).

Salinity is a sub-optimal condition due to excessive accumulation of soluble salts in the soil, such as NaCl, Na2SO4, and Na2CO3 (Li et al. 2006) causing electrical conductivity (EC) > 4.0 dS m-1 (equivalent to 40 m M NaCl) and the exchangeable sodium percentage (ESP) is less than 15 (Muscolo et al. 2011). Excessive salt concentrations (more than 200 mM) inhibit plant growth (Mukhtar *et al.*, 2018; Shahid *et al.*, 2018). Salinity causes plants to experience drought stress (osmotic stress) (Farooq *et al.*, 2015), reduces activity photosynthesis of leaves due to reduced amount of chlorophyll, and causes chlorosis and accelerates leaf aging (Hanin *et al.* 2016); reduces absorption of macro (N, P, and K) and micro (Ca and Mg) nutrients due to nutritional imbalance and ion toxicity (Zhou *et al.* ., 2018), and affects many aspects of plant metabolism which ultimately results in decreased growth and yield (Subiramani *et al.*, 2020). Salinity stress (EC 8-10 dS m^{-1}) is responsible for yield reductions of up to 20-50% in main food crops (wheat, rice, and maize) (Subiramani *et al.*, 2020) High yield loss in maize and wheat because they are both salinity sensitive crops (Zörb *et al.*, 2019).

High salinity in the soil is very detrimental, so mitigation measures must be taken. Various methods to overcome the problem of soil salinity have been developed by researchers, including chemical methods with ameliorant materials (Costa *et al.*, 2018; Gangwar *et al.*, 2020). The process is called amelioration, which means an attempt to improve saline soil by adding ameliorants. In the chemical method, gypsum and (CaSO$_4$.2H$_2$0), calcite lime (CaCO$_3$) and calcium chloride (CaCl$_2$) are used as neutralizing agents to remove Na+ in the root area (Hanay *et al.*, 2013; Ranjbar & Jalali, 2015). Organic fertilizers such as animal manure, sewage sludge compost, poultry manure, straw, and biochar were also added (Yang *et al.*, 2018; Leogrande & Vitti, 2019). These conventional methods, apart from being expensive and disruptive to agro-ecosystems

(particularly the method of adding chemicals) are also not practical in large areas and their success is not satisfactory (Damodaran *et al.*, 2019; Egamberdieva *et al.*, 2019). Especially for amelioration with organic fertilizer amendments, this method is able to increase the amount of organic matter (Liu *et al.*, 2017; Mitran *et al.*, 2016; Trivedi *et al.*, 2017) and improve soil physical and chemical properties (Yang *et al.*, 2018), but has very little effect in overcoming salinity stress when used alone without being mixed with other ingredients (Hanay *et al.*, 2013; Niamat *et al.*, 2019). Ameliorant materials that are cheap and can be used include zeolites which can suppress salt poisoning and improve soil physical and chemical conditions by binding toxic ions contained in salinity stress.

Zeolites are hydrated alumina crystalline silicates that contain three-dimensional alkalis or earth cation bases and have molecular-sized pores (Atikah, 2017). Zeolite can be used as a soil enhancer that can increase soil porosity (Micu *et al.* 2005), and play a role in reducing N leaching. According to Warmada and Titisari (2004), if Na+ saturation occurs from NaCl, Na will be absorbed by the zeolite to re-form Na-Zeolite (Na$_2$Al$_2$ Si$_3$O$_{10}$ 2H$_2$O). This happens because zeolite has a high CEC (between 120-180 me/100 g) which is useful as an adsorbent, binder and cation exchanger (Suwardi, 1998). Wang *et al.* (2012) reported that the application of zeolite on saline soil with a solids ratio of 30% by weight of the soil could reduce the sodium content from 563.0 ppm to 182.7 ppm. Experiments conducted by Noori *et al.* (2006), on *Rhapanus sativus* L. carried out in a greenhouse with soil salinity sources in the form of NaCl and Na$_2$SO$_4$ showed that the application of natural clinoptilolite as much as 0.06 kg/m2 could neutralize soil salinity and further increase crop yields. Research on shallots showed that the yield of shallots grown in saline soils was about 18.39% lower than in acid sulphate soils (Koswara, 2007). High salinity levels cause plants to have a low ability to absorb water from the soil, which can lead to limited plant growth and death (Provin & Pitt, 2017). Soil salinity of 2 dS m^{-1} can reduce onion yield by

12.82% (Cardon *et al.*, 2003).

Cabbage, including Chinese cabbage (*Brassica rapa* var. chinensis (L.) ranks third among various *Brassica* species due to its high economic potential and nutritional value. However, its growth and yield are greatly reduced under salinity conditions because this plant is sensitive to salinity (Ashraf & McNeilly, 2004). Therefore, understanding the effect of zeolite to improve saline soil for salinity-sensitive Chinese cabbage is necessary for the management of saline stressed soil. This study aimed to evaluate the effectiveness of natural zeolite as an ameliorant on improving soil properties, the growth, and yield of Chinese cabbage.

MATERIALS AND METHODS

Experiment sites and Research design

This research was conducted from September 2020 to early November 2020 in Bengkulu city with an altitude of 8.5 m above sea level. Based on climatological data from the Baai Island Climatology Station, the average daily temperature in September, October, and November 2020 was 26.8 ^{0}C, 26.6 ^{0}C, and 26.7^{0}C, respectively. The average humidity ranges from 84.4%, 84.6%, and 86.3% and the average light intensity is 65.7%, 53.3%, and 35.1%.

In thi study, the design used was a completely randomized design (CRD) with a single factor consisting of six levels, namely (1) T_0: neutral soil (non saline) as a control, (2) T_1 : soil + 6.9 g NaCl /10 kg soil, (3) T_2 : soil + 6, 9 g Na$_2$SO$_4$ /10 kg soil, (4) T_3 : soil + 3.2 g zeolite /10 kg soil, (5) T_4 : soil + 6.9 g NaCl /10 kg soil + 3.2 g zeolite /10 kg soil , and (6) T_5 : soil + 6, 9 g Na$_2$SO$_4$ /10 kg soil + 3.2 g zeolite /10 kg soil. Each treatment was repeated three times and each replication consisted of five polybags.

Preparation of Planting Media, Salinity Simulation, and Natural Zeolite Applications

Soil for research is classified as Ultisol soil order. Topsoil to be filled into polybags was taken from three different points at a depth of 0 –20 cm, air-dried, sieved using a 2 mm sieve, and put into a 10 kg polybag. Some of the soil was taken as a soil sample to analyze the C-organic content, the content of N, P, K, pH, and cation exchange capacity (CEC) of the soil.

The saline soil simulation was carried out using NaCl and Na$_2$SO$_4$ salt based on the method of Noori *et al.* (2006). The amount of salt given was adjusted to the treatment. Salt and soil were mixed well and then put into polybags and these polybags were then incubated for 14 days. Watering of the planting media in polybags is carried out until it reaches field capacity (soil moisture content of 70-80%). This soil moisture content was maintained until the end of incubation. At the end of incubation, six soil samples were analyzed including pH, electrical conductivity (EC), and soil CEC at the Soil Science Laboratory, Faculty of Agriculture, Bengkulu University.

After incubation, the growing medium was added with zeolite as an ameliorant. Before use, the zeolite was sieved through a 60 mesh sieve. Zeolite was given by mixing it with the planting media according to the treatment. Next, the growing medium was incubated for seven days. At the end of incubation, six soil samples were taken for analysis of pH, EC, and CEC at the Soil Science Laboratory, Faculty of Agriculture, Bengkulu University.

After completion of incubation, 40 g of manure was added to each polybag containing planting media and mixed thoroughly. These polybags were incubated again for seven days until they were ready for planting.

Planting and Crop Maintenance

Two weeks old of Chinese cabbage seedling of uniform size with 2-4 leaves) were planted in 10 kg polybags containing planting media according to treatment. The application of NPK Mutiara 16:16:16 fertilizer was given when the plants were 7 days after planting (DAP) at a dose of 500 kg/ha or 2.08 g/10 kg of soil.

Plant maintenance included regular watering twice a day in the morning and evening with each watering of 0.54 L/plant (50% at 7-14 DAP and 100% at 15-35 DAP), replanting, and

controlling insects and other plant-disturbing organisms. Harvesting was done when the plant is 30-35 DAP when the bottom two leaves have turned yellow.

Observations of plant growth were carried out on plant height, the number of leaves, leaf greenness level using a SPAD meter, fresh weight of roots, dry weight of roots, plant dry weight, stalk length, and yield on fresh leaf weight and plant fresh weight. At the end of the study, soil analysis was carried out on CEC, pH, EC, and C-organic. Soil pH was measured using pH meter at ratio 1:2.5 of soil and distilled water, soil total nitrogen using Kjeldahl Method , exchangeable Al using titration method after extertaion of 1N KCl, organic-C using Walkly and Black Method, cation exchange capacity (CEC) using 1N ammonium acetate extraction, and soil bulk density using ring sample method.

Data analysis

Data analysis was performed with SPSS 21.0 software (SPSS Inc.). ANOVA at 5% level and 5% BNT average difference test were used to determine the effect of treatment.

RESULTS AND DISCUSSION

Soil Chemical Properties

The application of natural zeolite changed the chemical properties of saline soils (EC, pH, and soil CEC) (Table 1). The EC of saline soils decreased from the moderate salinity category (EC = 4-8 dS/m) to the low salinity category (EC = 2-4 dS/m). The decrease occurred because of the ability of the zeolite as a cation exchanger.

Cations in the soil solution that can be exchanged by zeolites mainly include sodium (Na^+), potassium (K^+), and calcium (Ca^{2+}) (Wajima et al. 2010). With these results, it is concluded that zeolite can reduce soil salinity, as well as water salinity (Gibb et al., 2017). The ability of natural zeolites to absorb Na+ ions has been proven by Wajima et al. (2010) and Wibowo et al. (2017) especially Na+ in seawater. According to Wajima et al. (2010), zeolite can reduce the Na+ content in seawater, but the ability to reduce Cl^- and SO_4^{2-} was small (only 20% and 30%, respectively).

The addition of zeolite to NaCl and Na_2SO_4 saline soil did not increase soil pH (Table 1). The results of this study contradict the results reported by Aainaa et al. (2015) who stated that the application of zeolite increased soil pH through the exchange of H+ ions in the soil solution with zeolite cations. The cause of the failure of this increase in pH was due to the initial low pH of the soil used in this study so that the Al and Fe content tended to be high. Low soil pH reactivity (less than 5.5) is determined by Al hydrolysis so that the soil pH remains unchanged or changes little despite the addition of zeolite (Aaina et al., 2015).

Application of natural zeolite increased soil CEC (Table 1). The increase in CEC occurred because Na+ from NaCl in saline soil was absorbed by the zeolite to re-form Na-Zeolite (Na_2Al_2 Si_3O_{10} $2H_2O$) and exchanged for Ca^{2+}

Table. 1 Electrical conductivity (EC), pH, and CEC of soil after addition of zeolite.

Treatment	EC (dS m^{-1})	Category	pH	Category	CEC cmol(+) kg^{-1}	Category
Control	2,78	Low	5.3	Slightly acid	14.72	Low
Soil + 6.9 g NaCl /10 kg soil	4.10	Medum	6.0	Slightly acid	10.15	Low
Soil + 6.9 g Na$_2$SO$_4$/10 kg soil	4.20	Medium	5.9	Slightly acid	12.69	Low
Soil + 3.2 g Zeolite / 10 kg soil	3.20	Low	6.0	Slightly acid	15.48	Low
Soil + 6.9 g NaCl /10 kg soil + 3.2 g Zeolite /10 kg soil	3.66	Low	6.0	Slightly acid	12.94	Low
Soil + 6.9 g Na$_2$SO$_4$/10 kg soil + 3.2 g Zeolite /10 kg soil	3.10	Low	6.0	Slightly acid	15.24	Low

(Wajima *et al*., 2010). The exchange of Na^+ with Ca^{2+} can occur because zeolite has a high CEC (between 120-180 me 100 g^{-1}) which is useful as an adsorbent, binder, and cation exchanger and contains exchangeable cations such as Mg^{2+}, Ca^{2+}, K+, and Na+ (Suwardi, 1998).). The research results of Wajima *et al*. (2007) also reported that natural zeolites can be used to reduce NaCl in seawater through ion exchange with other cations, such as K+, NH4+, Mg^{2+}, and Ca^{2+}. Apart from ion exchange, the mechanism that regulates the process of reducing salt content in saline soils by zeolites is mainly salt adsorption and storage (Aainaa *et al*. 2015).

Components of Growth and Yield

NaCl salinity stress inhibited plant growth more than Na_2SO_4 salinity stress. NaCl salinity stress decreased plant height (23%), the number of leaves (22%), fresh root weight (165%), and root dry weight (170%), while Na_2SO_4 salinity stress only decreased leaf number (23%) compared to non-saline soil (control) (Table 2). Of these two salinity stresses, Cl- salinity stress inhibited Chinese cabbage growth more than SO4- salinity stress. Research by Curtin *et al*. (1993) on barley (*Hordeum vulgare*) obtained the same result that Cl- salinity stress inhibited growth more than SO4- salinity stress. Barley plant growth under SO4- salinity stress was significantly

better (mean 17%) than Cl- salinity stress.

According to Mor & Manchanda (1992), this occurs because the excessive accumulation of Cl- in plant tissues causes disruption of nutrient absorption such as inhibition of phosphate absorption. Curtin *et al*. (1993) further stated that the response of plants to salinity depends on the type of salt (sulfate or chloride) that contributes to salinity as well as the concentration of total electrolytes. Decrease in plant height due to salinity stress was also reported by Mathur *et al*. (2006) on *Vigna aconitifolia* L., Jamil *et al*. (2007) on radish (*Raphanus sativus* L.), and Taffouo *et al*. (2010) on cowpea (*Vigna unguiculata* L.). A decrease in the number of leaves due to salinity stress was also reported by GhassemiSahebi *et al*. (2020), who stated that the decrease in leaf number was initially caused by a decrease in leaf area which in turn reduced the production of photosynthetic products for the formation of new leaves.

A decrease in plant growth initiated by a decrease in root weight due to salinity stress was also reported by Jbir *et al*. (2001) and Arif *et al*. (2019). According to West *et al*. (2004), this decrease in root weight occurs because salinity stress causes inhibition of root elongation and branching. Puvanitha & Mahendran (2017) also reported that salinity reduces the dry weight of plant roots which can occur as a result of the combination of osmotic

Table 2. Effect of amelioration of saline soil with natural zeolite on Chinese cabbage growth

Treatment	PH (cm)	NL (leaf)	LG (SPAD Index)	RFW (g)	RDW (g)
Control	24.78 ab	18.11 ab	34.37 a	5.89 ab	0.62 ab
Soil + 6.9 g NaCl /10 kg soil	20.22 c	14.89 c	34.68 a	2.22 c	0.23 c
Soil + 6.9 g Na2SO4/10 kg soil	22.00 bc	14.78 c	34.46 a	3.33 bc	0.37 bc
Soil + 3.2 g Zeolite / 10 kg soil	28.17 a	20.44 a	35.22 a	7.44 a	0.76 a
Soil + 6.9 g NaCl /10 kg soil + 3.2 g Zeolite /10 kg soil	25.72 ab	17.17 b	34.62 a	6.69 a	0.53 ab
Soil + 6.9 g Na2SO4/10 kg soil + 3.2 g Zeolite /10 kg soil	25.95 a	18.56 ab	35.04 a	5.89 ab	0.63 ab

Note: Numbers followed by the same letter in the same column are not significantly different in the 5% LSD test. PH = Plant Height, NL = Number of Leaves, LG = Leaf Greenness, RFW = Root Fresh Weight, RDW = Root Dry Weight

and specific effects of Na+ and Cl⁻ ions. According to Munns (2002), an increase in osmotic pressure due to high concentrations of dissolved salts in the soil, especially Na+ which can be exchanged, accompanied by inhibition of root growth, ultimately inhibits nutrient absorption and water absorption so that the amount of water entering the roots decreases and results in depletion of the amount of water supply in the plant. Inhibition of nutrient absorption and water absorption due to salinity stress reduces the number and area of leaves that function in the photosynthesis process (Munns, 2002).

Amelioration of saline NaCl soil with natural zeolite can reduce the effect of salinity stress by lowering soil EC to the same value as non-saline soil EC (control) (Table 1). This decrease in EC has the effect of increasing plant growth to match the growth of plants on non-saline soils (Table 2). With amelioration using natural zeolite, plant growth increased 27% for plant height, 15% for the number of leaves, 201% for fresh root weight, and 130% for root dry weight compared to saline NaCl soil. Meanwhile, amelioration of saline Na_2SO_4 soil with zeolite only increased plant height and the number of leaves (Table 2). According to Mor & Manchanda (1992), this occurs because the excessive accumulation of Cl- in plant tissues inhibits growth significantly, while the accumulation of SO_4 has less impact so that plant growth remains normal. As a result, the addition of zeolite for the amelioration of Na_2SO_4 saline soil has less impact on increasing growth.

An increase in plant growth due to the amelioration of zeolite on saline soils was also reported by Khan *et al.* (2011) and GhassemiSahebi *et al*. (2020). According to Khan *et al.* (2011), plant height and number of soybean leaves increased significantly with the application of zeolite on saline soil. Ghassemi Sahebi *et al*. (2020) reported that the application of zeolite also significantly increased leaf area and biomass of sorghum. Other researchers (Kavoosi, 2007) reported that zeolite application significantly increased N uptake, nucleic acid formation, amide, and also cell multiplication, which further increased leaf area and height of rice plants. Kavoosi (2007) further stated that the use of zeolites can increase nutrient uptake and increase cell multiplication, which in turn encourages the formation of higher leaf area and biomass.

In addition to inhibiting growth, NaCl salinity stress reduced stalk length and plant dry weight (Table 3). NaCl salinity stress reduced stalk length up to 32% and reduced plant dry weight up to 131%. A decrease in plant dry weight was also reported by Puvanitha & Mahendran (2017) in rice and Noori *et al*. (2006) on radishes. According to Puvanitha & Mahendran (2017), a decrease in shoot dry weight occurs as a result of the reduced number of leaves formed. The low number of leaves causes photosynthesis and the accumulation of dry matter is reduced. This decrease in yield under conditions of salinity stress may occur due to stunted growth as a result of reduced water uptake, the toxicity of sodium and chloride in shoot cells, and reduced photosynthesis (Juan *et al*., 2005). Meanwhile, according to Neumann (1997), a decrease in shoot dry weight occurs as a result of inhibition of root growth and the ability of roots to absorb water and soil nutrients.

In contrast to NaCl salinity stress, Na_2SO_4 salinity stress did not affect the decrease in yield and its components. According to Mor and Manchanda (1992), this occurs because the accumulation of SO_4 has less impact so that plant growth and yields remain normal. As a result, the addition of zeolite for the amelioration of saline Na_2SO_4 soil has less impact on increasing growth. Meanwhile, the excessive accumulation of Cl- in plant tissues inhibited plant growth and yield significantly.

The application of zeolite as an ameliorant reduces the detrimental effects of both NaCl and Na_2SO_4 salinity stress, indicated by increasing yields and yield components of plants (Table 3). With the application of zeolite on NaCl saline soil, yield and yield components increased by 39% for stalk length, 172% for plant fresh weight, 174% for leaf fresh weight, 133% for plant dry weight, and 23% for leaf dry weight up to its value. as high as control (non-saline soil) for the same

Table 3. Effect of amelioration of saline soil with natural zeolite on yield and yield components of Chinese cabbage.

Treatment	SL (cm)	PFW (g)	LFW (g)	PDW (g)	LDW (g)
Control	7.79 ab	108.11 bc	40.78 bc	6.75 ab	2.96 bc
Soil + 6.9 g NaCl /10 kg soil	5.88 c	52.44 c	18.11 c	2.92 c	1.27 c
Soil + 6.9 g Na$_2$SO$_4$/10 kg soil	7.05 b	104.22 bc	30.67 bc	4.14 bc	1.83 c
Soil + 3.2 g Zeolite / 10 kg soil	7.89 ab	187.44 a	69.00 a	7.08 a	4.07 ab
Soil + 6.9 g NaCl /10 kg soil + 3.2 g Zeolite /10 kg soil	8.17 a	142.44 ab	49.56 ab	6.81 ab	4.28 ab
Soil + 6.9 g Na$_2$SO$_4$/10 kg soil + 3.2 g Zeolite /10 kg soil	7.93 ab	161.89 ab	46.22 ab	7.87 a	5.07 a

Note: Numbers followed by the same letter in the same column are not significantly difference in the 5% LSD test. SL = Stem Length, PFW = Plant Fresh Weight, LFW = Leaf Fresh Weight, PDW = Plant Dry Weight, LDW = Leaf Dry Weight

variable. Similar results were reported by Noori *et al.* (2006) on radish (*Raphanus sativus* L.). According to Noori *et al*. (2006), the application of zeolite can withstand harmful NaCl salt so that the salt does not enter the plant through the roots. Meanwhile, amelioration with zeolite in saline Na$_2$SO$_4$ only increased plant dry weight and leaf dry weight by 90% and 177%, respectively.

The increase in yield and its components in this study occurred as a result of the zeolite's ability to absorb and retain the dissolved ions (Na+, Cl-, and SO$_4^{2-}$) through ion exchange and its porous nature. This characteristics prevent the dissolved ions from accumulating in the root zone which can poison them. The results of previous studies have proven the reduction of Na+ content in the soil by using zeolites (Wajima *et al*., 2010).

The application of natural zeolite to non-saline soils increases the soil's ability to retain nutrients around the root zone and prevent them from being lost through leaching (Noori *et al*., 2006). This causes the use of N and K fertilizers to be more efficient because the fertilizer used is reduced while the yield is the same or even higher. This is the reason why the application of zeolite on non-saline soil gave higher growth and yield of biomass than control.

CONCLUSION

Plant growth (particularly plant height, the number of leaves, fresh root weight, and root dry weight) and yield of Chinese cabbage and its components (especially stalk length and plant dry weight) were more inhibited due to NaCl than due to Na$_2$SO$_4$ salinity stress. NaCl salinity stress occurs through an increase in soil EC. The application of natural zeolite as an ameliorant to soils salinity stressed by NaCl increased plant growth as measured by plant height, the number of leaves, fresh and dry weight of roots, and plant yields by measuring leaf stalk length, plant fresh weight, leaf fresh weight, plant dry weight, and leaf dry weight compared to soil stressed by Na$_2$SO$_4$ salinity.

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