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Soil properties and shallot yield responses to different salinity levels

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ABSTRACT

Successful management of saline water could have significant potential for agricultural development in many areas, particularly in freshwater-scarce regions. To date, the effect of salinity on shallot (*Allium Cepa* L.) yield and growth parameters has not been studied in detail specifically for local varieties cultivated in Inceptisols. Therefore, the present study was designed to evaluate the effects of different levels of irrigation-water salinity (0, 1, 2, and 3 dS m^{-1}) on soil chemical properties, the growth, and yield of local shallot varieties. The experiment was conducted in pots using a randomized plot design with two factors and three replications. The results showed that increases in salinity level affected increases soil pH, exchangeable Na percentages, and plant height growth. Nevertheless, bulb number and weight, soil exchangeable Ca and Mg, soil organic carbon, and sodium adsorption ratio (SAR) was not significantly affected. The findings of the present study suggest that the local varieties—*Brebes* and *Purbalingga*—with irrigated salinity levels up to 3 dS m^{-1} can be tolerated for shallot cultivation in Inceptisols.

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1. Introduction

Crop yields and agricultural productivity are influenced by irrigation practices, especially water salinity levels (Li et al., 2019). Allocating freshwater to consumption by humans and livestock leaves limited resources for agricultural irrigation (Wu et al., 2016; Flörke, Schneider, & McDonald, 2018). Therefore, to increase crop yields, it is necessary to seek irrigation alternatives to freshwater. Saline water has long been used in Indonesia especially in agricultural applications (Jalali, Kapourchal, & Homaee, 2017), and its use poses a variety of challenges. Plants cultivated near the sea are subject to saline intrusion by seawater, and over time, the salinity level may induce salt accumulation in the root zone (Li et al., 2019). The growth and yield reduction of crops in areas of the world prone to saline accumulation is a serious issue (Ashraf, 2009). This is especially true in Indonesia where, according to the Indonesia Statistical Agency (BPS), in 2014, 24,000 ha of shallot crops in Brebes Regency and 150 ha of shallot crops in Purbalingga Regency—both planted in *Allium* sp. and both located near the sea—experienced production failures caused by seawater intrusion (BPS, 2019).

Depending upon the plant species, salinity levels, and ionic composition of the salts decrease plant growth and yields (Rabie, Aboul-Nasr, & Al-Humiany, 2005). Turhan, Kuscu, Özmen, and Demir (2014) examined the effect of different soil salinity levels (1.60, 2.87, 4.14, 5.41, 6.68, and 7.95 dS m^{-1}) on garlic, and found that garlic can be grown satisfactorily with increased soil salinity up to 4.14 dS m^{-1}, but the amount of total dry matter decreased considerably with increasing soil salinity above that point. Salt tolerance in plants is a complex phenomenon that involves morphological and developmental changes as well as physiological and biochemical processes. Previous studies have shown that the *Allium* species of shallot is a crop moderately sensitive to salt stress (Kadayifci, Tuylu, Ucar, & Cakmak, 2005; Kiremit & Arslan, 2016). Management of saline water for agricultural irrigation is a major challenge to efforts to enhance crop growth and yields. Therefore, this study examines the effects of salinity on Inceptisols chemical properties, and the growth and yield of two shallot cultivars under pot-growing conditions.

2. Materials and Method

2.1. Experiment design

The experiment was conducted from June to September 2018—a period of 99 days after planting (DAP)—at the research station of Agriculture Faculty located in Karanganyar Regency, Indonesia. The average minimum/maximum temperatures and relative humidity were calculated at 28°C/32°C and 65–90%, respectively. The study was conducted using Brebes and Purbalingga cultivars, the most commonly gown shallot varieties in Indonesia. The cultivars have a stem length of approximately 25–44 cm, and yields have been reported to range between 10 t ha^{-1} (Yuliani, 2017). Shallot seedlings were sown under polyethylene pots, three plants per pot, then filled with 15 x 10^3 $g.pot^{-1}$ Inceptisols with a sandy/clay/loam texture consisting of sand (13.9%), clay (43.8%), and silt (42.1%). Soil physical and chemical properties presented in Table 1. Following Sumarni, Rosliani, and Suwandi (2012), compost (71 g pot^{-1}) and phosphorus (2.1 g pot^{-1}) fertilizer were applied to the soil seven days before planting. Solid fertilizer—1.78 g of urea, 1.27 g of $(NH_4)_2SO_4$, and 1.42 g of KCL per pot—was applied 30 days after planting. All irrigation was performed with tap water (0 dS m^{-1}) as a control. Saline irrigation treatments were administered from planting through harvesting. Three levels of salinized water were produced by diluting salt with tap water (0.64, 1.28, and 1.92 g $liter^{-1}$ to equal 1, 2, and 3 dS m^{-1}, respectively). The treatments included two cultivar varieties (Brebes and Purbalingga) and four levels of salinity (T0 = 0 dS m^{-1}, T1 = 1 dS m^{-1}, T2 = 2 dS m^{-1}, and T3 = 3 dS m^{-1}) with three replications in a completely randomized design.

2.2. Soil chemical properties

Soil pH was determined using a 1:2.5 soil to water solution ratio and a pH meter (Tetsopgang & Fonyuy, 2019). Electrical conductivity was measured using a 1:5 soil to water solution ratio using an electroconductivity meter (Abd-Elwahed, 2019); soil organic matter was determined by the Walkey and Black method; and total nitrogen (N) was measured using the Kjeldahl method (Bremner, 1965). Soil total phosphorus (P) was measured using molybdenum antimony blue colorimetry after the $HClO_4$ digestion of soil extracts (Murphy & Riley, 1962). The exchangeable cations (Ca^{2+} and Mg^{2+}) were determined by Atomic Absorption Spectrophotometer (AAS) (David, 1960; Angassa et al., 2012). Na^+ was measured by flame-photometer, as was the determination of soil exchangeable calcium (Ca), magnesium (Mg), and sodium (Na) (Carson, 1980; Moyin-Jesu, 2007). Sodium Adsorption Ratio (SAR) was calculated using the following equation (Murtaza, Ghafoor, & Qadir, 2006):

$$SAR = C_{Na}/[(C_{Ca}+C_{Mg})/2]^{1/2} \quad \text{...} \quad (1)$$

where C_{Na}, C_{Ca}, and C_{Mg} are the concentrations of the Na^+, Ca^{2+}, and Mg^{2+} in mmol L^{-1}.

2.3. Crop measurement

Seeds were initially harvested at 88 DAP and there were three subsequent harvests at three to four days intervals, depending on plant conditions and weather, until 99 DAP. Mini bulbs are tubers produced by shallots after the seeds are harvested. Measurements were made in vegetative and generative phases. Variables and time of observation were as follows: Observations were made at 63 DAP. The number of flower stalks that appeared with fully bloomed flowers on all plants in each treatment plot were counted. Shallot seed weights were determined by weighing the seeds produced in all kernels in each treatment plot.

Additional observations were made at harvest after seed processing was completed following the stages set forth by Istiqomah, Barunawati, Aini, and Widaryanto (2019), the harvested flowers were dried and separated from the stover, then seeds in the kernel were manually extracted and weighed. The harvested tubers were weighed as part of the shallot seed harvest, and tubers weight produced per plot, per treatment was recorded. Root dry weight and above-ground biomass dry weight were determined through destructive sampling and weighing the harvested fresh weight before being placed into the oven overnight at 60°C to derive dry weight for the measurement the following day.

2.4. Statistical analysis

The effects of irrigation-water salinity on soil chemical properties and shallot growth and yield were evaluated using the statistical software SPSS and were analyzed by two-way ANOVA followed by Duncan Multiple Range Test (DMRT) to determine statistically significant differences between means ($p \leq 0.05$).

3. Results

3.1. Soil chemical properties of saline soil

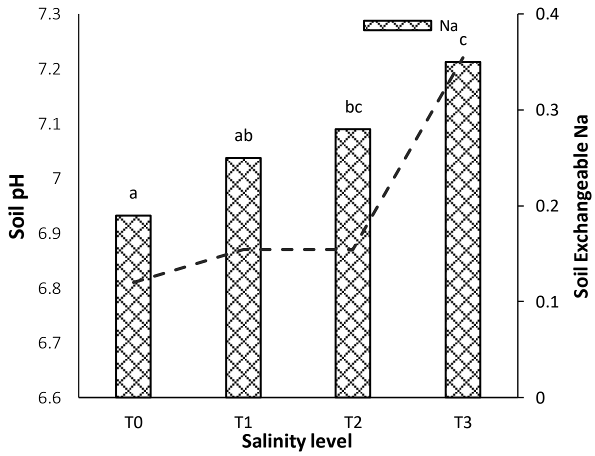

Figure 1. Soil pH and exchangeable Na as affected by different levels of salinity.

The results showed that the level of salinity affected soil chemical properties. The soil exchange of Na^+ increased with the increase of soil salinity; the exchange of Na^+ was greater at T3 > T2 > T1 > T0. The treatments also revealed a significant difference in chemical properties; soil pH increased with the increase in salinity. At T0, pH was 6.81, at T1 and T2, pH increased to 6.87, and at T3, pH rose to 7.22 (see Figure 1). The increase in pH is caused by H^+ ions released from the exchanger complex by the influence of other soluble cations in the applied saline water (Mahrous, Mikkelsen, & Hafez, 1983; Akhwan, Sulistyaningsih, & Widada, 2012).

3.2. Plant chemical properties, growth, and yield in saline soil

Table 1. Soil chemical and physical properties at 30 cm soil depth

Soil Properties	Values
EC (dS m^{-1})	0.07
pH	6 - 8
N total (%)	0.18
Phosphorus availability (mg Kg^{-1})	3.99
Exchangeable Na (me 100 g^{-1})	0.66
Exchangeable K (me 100 g^{-1})	0.17
Exchangeable Mg (me 100 g^{-1})	1.05
Exchangeable Ca (me 100 g^{-1})	8.03
C-Organic (%)	1.06
Sand (%)	13.97
Silt (%)	42.18
Clay (%)	43.85
Soil depth (cm)	30 cm

Table 2. Analysis of variance of the effects of salinity levels on soil properties.

Soil Properties	Salinity
pH	0.05 *
Electrical conductivity	0.88 ns
C-Organic	0.69 ns
Exchangeable Na	0.01*
Exchangeable Ca	0.06 ns
Exchangeable Mg	0.11 ns
SAR	0.25 ns

Note: SAR= sodium adsorption ratio; ns=are no significant; *and **=significant at P<0.05 and **P<0.01

As shown in Figure 2, plant chemical properties were assessed as part of this study. The nutrient uptake by plants generally decreased with the increase of salinity levels. For example, N levels fell as follows: 2.67%, 2.53%, 2.51%, and 2.23% for T0, T1, T2, and T3, respectively. Kalium levels ranged from: 2.16%, 1.70%, 1.66%, and 1.59% for T0, T1, T2, and T3, respectively. The levels of P remained fairly stable, 0% at T0, and 0.01% at T3. Increases in salinity levels significantly affected the growth of shallots as demonstrated by the inverse relationship between salinity increases and inhibited plant heights: 33.37 cm, 32.13 cm, 27.68 cm, and 27.57 cm for T0, T1, T2, and T3, respectively.

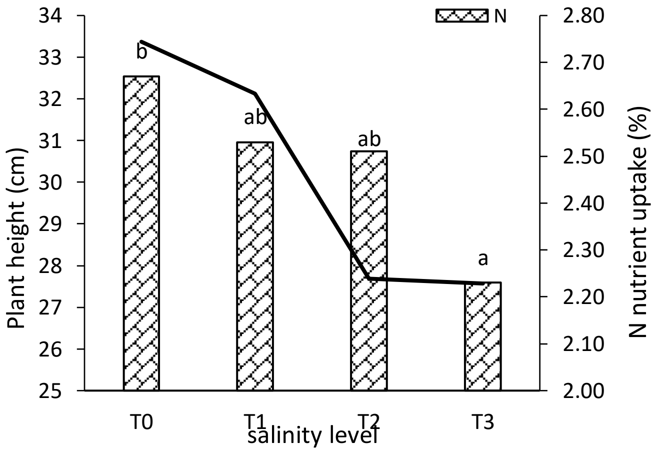

Figure 2. Plant height and N Nutrient uptake condition at the different levels of salinity

The yield parameters were not significantly affected by increases in soil salinity, but T1, with a salinity level of 1 dS m^{-1}, had a higher number of bulb pieces (9-piece bulbs) and fresh and dry bulb weights (32.59 g pot^{-1} and 26.67 g pot^{-1}) compared to T0, which had 7-piece bulbs, fresh and dry bulb weights of 32.43 g pot^{-1}, and 26.55 g pot^{-1}. In this study, a small increase in salinity level did not significantly affect biomass parameters such as fresh and dry of stem and bulb weights, respectively; however, increases in soil salinity beyond T1 caused a reduction in biomass from a high of 51.41, 32.30, 32.43, and 26.55 g pot^{-1} (T0) to a low 40.39, 25.95, 28.73, and 24.27 g pot^{-1} (T3).

Table 3. Effect of salinity level on plant parameters

Analysis	Treatments (dS m^{-1})					
	T_0 (0.0)	T_1 (1.0)	T_2 (2.0)	T_3 (3.0)	Mean	F Test
Plant height (cm)	33.37^b	32.13^b	27.68^a	27.57^a	30.19	0.00**
Stem fresh weight (g pot^{-1})	51.41^a	45.62^a	35.26^a	40.39^a	43.17	0.43 ns
Stem dry weight (g pot^{-1})	32.30^a	28.77^a	24.53^a	25.95^a	27.89	0.63 ns
Number of bulbs	7.17^a	9.67^a	7.33^a	5.83^a	7.50	0.45 ns
Bulb fresh weight (g pot^{-1})	32.43^a	32.59^a	22.19^a	27.70^a	28.73	0.68 ns
Bulb dry weight (g pot^{-1})	26.55^a	26.67^a	19.60^a	24.27^a	24.27	0.65 ns
N (%)	2.67^b	2.53^{ab}	2.51^{ab}	2.23^a	2.67	0.08 ns
P (%)	0.01^a	0.01^a	0.00^a	0.01^a	0.01	0.24 ns
K (%)	2.16^b	1.66^a	1.59^a	1.77^{ab}	1.79	0.04*

Notes: The mean followed by the same letter indicates no significant difference in the same row (P = 0.05) by the DMRT test; ns= no significant; *and **=significant at P<0.05 and **P<0.01, respectively

4. Discussion

The salinity levels of irrigation fluids influenced soil pH and exchangeable Na (Table 2); increasing salinity resulted in both soil pH and an increase in exchangeable Na (Figure 1). The higher soil pH is caused by the release of H^+ ions from the complex influence of other soluble cations in the saline soil (Mahrous et al., 1983; Akhwan et al., 2012); the higher Na^+ concentration was created simply by the addition of greater quantities of saline (0, 1, 2, and 3 dS m^{-1}). Plant height and Na adsorption were the only growth parameters affected by the salinity level of irrigation waters (Table 3), it is suitable with a previous study that the toxic effect of Na inhibited plant growth (Adiku, Renger, Wessolek, Facklam, & Hecht-Bucholtz, 2001). In addition, Yuliani (2017) observed that some varieties of shallot require ample C-organic and exchangeable Na, Ca, and Mg for growth and yield production.

Also, soil pH is important; it governs the availability of nutrients (Zaki, Komariah, Rahmat, & Pujiasmanto, 2018) and the import of fertilizer materials. For a majority of plants, the optimum pH for growth is between 6.5 and 7 (Gill et al., 2015).

This study showed that the level of salinity did not significantly affect growth and yield. Kiremit and Arslan (2016) reported similar findings: that varieties of *Allium porrum* L. can tolerate salinity in the field. According to Mangal, Lal, and Hooda (1989), onion bulbs and vegetative growth declined only when soil salinity values exceeded 4.0 dS m^{-1}. Previous studies have shown that salinity tolerance is a cultivar-dependent trait (Khaleghi, Karamnezhad, & Moallemi, 2019), and there is a similar response between the gametophytic and sporophytic phases to abiotic stresses such as salinity (Koval, 2004; Ravikumar, Patil, & Salimath, 2003; DeMicco, Scala, & Aronne, 2006). A significant lack of any nutrient can cause a decrease in the growth and development of plants. Levels of plant N—a very important nutrient in plant growth (Brady & Weil, 2002) decrease in response to increasing salinity conditions.

5. Conclusion

Irrigation water with high salinity levels leads to high soil pH and an increase in exchangeable Na. The growth of shallot (*Allium cepa* L.) varieties *Brebes* and *Purbalingga* in this study was affected as reflected in decreased plant height; nitrogen as a significant growth factor, was inhibited and decreased at the T3 level of salinity—3 dS m^{-1}. Nevertheless, the high level of salinity did not significantly affect yield components such as the number of bulbs, and fresh and dry bulb weight. This study shows that the growth and yield of local shallot varieties *Brebes* and *Purbalingga* are tolerant of salinity levels up to 3 dS m^{-1}.

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Declaration of Competing Interest

The authors declare no competing financial or personal interests that may appear and influence the work reported in this paper.

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