Soil properties, growth and spears yield quality of five asparagus cultivars grown in tropical soil affected by NaCl applications

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Abstract. To cultivate asparagus (Asparagus officinalis L.) in the tropics is constrained by high temperature and humidity that are potentially stimulating the development of soil-borne diseases. The research was aimed to observe the NaCl applications effects on properties of soil physicochemical, growth and spears yield quality of asparagus in the tropical medium elevation (730 meters above sea levels). The experiment used Split-Plot Design with three levels of NaCl concentrations (1, 2 and 3 g L⁻¹, respectively) as the main plot and five asparagus cultivars (Atlas F1, de Paoli F1, Jing Green F1, San Knight F1 and Jaleo) as the subplot with three repetitions. No interaction was found between NaCl applications and asparagus cultivars at 12 weeks after planting. NaCl concentrations significantly increased soil electrical conductivity (2.14 - 2.68 dS m⁻¹); levels of soil Na⁺ (1.77 - 2.34 cmol kg⁻¹) and Cl⁻ (25.02 - 27.79 mg kg⁻¹), but decreased the levels of Ca²⁺ and Mg²⁺, respectively by 1.23 and 1.44 cmol kg⁻¹. Higher spears number and weight of asparagus were produced by cultivars of Jaleo (54.3% and 66.4%, respectively) and Atlas F1 (50.9% and 62.6%, respectively). The conclusion shows that Jaleo and Atlas F1 can adapt to the tropical medium environment due to their genetic traits.

1. Introduction

In Indonesia, asparagus (Asparagus officinalis L.) is considered as a unique annual plant and valued as a favourite luxury vegetable because of its high nutritional and mineral content. In asparagus spears, the high contents of minerals, vitamins and proteins are found [1], although this is very determined by environmental factors especially availability and content of soil nutrients and genetic traits of the plant [2].

In the tropical region [3] reported that high temperature and humidity can stimulate the development of soil-borne disease in the rooting zone of plants as Fusarium oxysporum sp. and Meloidogyne spp. Therefore, cultivation methods that are suitable for the tropical climate in increasing asparagus production to meet consumer demand are needed. Part of the management strategies among others is the use of a UV-plastic shade to avoid excessive rainfall and NaCl application to alleviate the attack of the soil-borne pathogen. [4] and [5] reported that NaCl can suppress Fusarium sp. disease
through fungistatic influence or crop endurance manipulation. It is known that Cl\(^-\) is the main active osmotic solute in the vacuoles and is involved in plant turgor- and osmoregulation. Meanwhile, the movement of Cl\(^-\) in the soil is determined by the flow of water so that it might be able to support the mechanism of plant resistance [6].

According to [7] applications of NaCl 1,120 kg ha\(^{-1}\) in asparagus plants reduced the attack of *Fusarium sp.* and suppressed weed species. [8] also showed that the application of NaCl 1 tons ha\(^{-1}\) increased spears yield of asparagus in the second period by 37% than without NaCl application. The NaCl concentration of 4000 kg ha\(^{-1}\) was applied within four months may increase asparagus yield [9]. On the other hand, excessively NaCl application into the soil can cause damage to soil physicochemical properties, contamination of groundwater and disruption of crop rotation systems [10].

Following the statement of [11] several factors influence the accumulation of salt in the soil, the most important is the balance of evapotranspiration with annual rainfall. In irrigated soils, the salt balance depends on the concentration of salt in irrigation water and on the total water applied. Meanwhile, the rate at which plants use water is determined by the stage of plant growth, weather, topography and soil properties that are most susceptible to salt accumulation, namely in the root area.

Unlike most other vegetables, asparagus belongs to a group of plants that are tolerant of salinity, deep-rooted and takes water from large volumes of soil. In line with this, it is known that the accumulation of salt in the root environment can lead to the osmotic pressure increased and interfere the homeostasis of cell ion by stimulating inhibitions in the absorption of essential plant nutrients [12] but accumulating the uptake of Na\(^+\) and Cl\(^-\) [13]. Recent research and hybridization have brought a new generation of all-male asparagus cultivars that have been bred for disease resistance and higher yields. Therefore, information about suitable and tolerant asparagus plants for salt levels is necessary to choose more cultivars that can grow well in the tropics.

Preliminary research in 2017 with two asparagus cultivars of Atlas F1 and Jaleo was conducted in the Indonesian tropical highland (1000 mASL, Lembang area). The results showed that the highland environment supported asparagus growth well and harvests could be sustainable following the growth of asparagus spears, which eventually its quantity and quality decreased [14]. Based on those data, further research was aimed to find out the suitable asparagus cultivars that can be cultivated in the medium elevation by adding NaCl as soil ameliorant. To evaluate the changes in soil physicochemical properties and the response of asparagus growth, yield and quality of spears from five asparagus cultivars in the tropical medium elevation (730 mASL), various NaCl concentrations were applied in this study.

2. Material and Methods

2.1. Experimental site characteristics

Field experiments were done during the rainy and dry seasons in 2018 under a UV-plastic shade in the medium elevation at 730 m ASL of the experimental station of Agriculture Faculty, Universitas Padjadjaran. The climate is classified as humid tropical which the maximum temperature ranged from 30.0°C to 35.7°C; while the minimum temperature varied from 17.5°C to 23.9°C and the average relative humidity (RH) varied from 73.4% to 92.2%.

2.2. Treatments and experimental design

The experiment used Split-Plot Design with three levels of NaCl concentrations (1, 2 and 3 g L\(^{-1}\), respectively) as the main plot and the subplot was the four-months-old seedlings from five introduced asparagus cultivars obtained from Rijk Zwaan Seeds Ltd., De Lier, the Netherlands (i.e. Atlas F1 from California Asparagus Seed and Transplant USA; de Paoli F1 Hybrid from Atlas Seeds, BJ. Co. Ltd. Beijing; Jing Green Hybrid F1 from Beijing Academic of Agriculture and Forestry Sci. China; San Knight Hybrid F1 from Atlas Seeds, BJ. Co. Ltd and Jaleo from Vilmorin, France). The trial was conducted triplicate over the seasons.

Four-months-old seedlings of five asparagus cultivars were planted in a double row system (zig-zag) in a ditch on a soil bed of 90cm x 700cm. The planting distance was 40cm x 50cm and planting
depth was 20cm. Each row was spaced on 0.5m. During all seasons, soil moisture levels and weed growth were controlled by putting plastic mulch around the beds and along the trench. Other materials included composted sheep's manure, NPK compound fertilizers of 25:7:7 and 16:16:16. Concentrations of NaCl solution were given twice weekly and applied in the middle of the planting trench (30 cm) each time of watering of 10 L per plot (5 m x 1 m), started from 4 to 16 WAP.

Asparagus spears were started to be harvested at 12 WAP with the reason that asparagus plants still had fewer ferns causing the plant to grow next new spears and it was expected that the first harvested spears reach a marketable size with A grade [14]. Harvesting was done daily by cutting 28cm asparagus green spears of more than 0.8cm diameter, followed by grading into marketable (A and B) and unmarketable spears (C).

2.3. Measurement of soil and plant growth parameters
Based on the analysis methods commonly used and described in [15], the determination of organic-C values, pH and EC in manure was measured. Sampling was performed throughout the experiments. As many as 3–5 sub-soil samples were taken from each plot, mixed and analysed in the accredited commercial laboratory using the standard procedures described in methods of soils analysis [16]. Preparation of soil extracts to be analysed was used for each air-dry sample with a size of 2 mm. The gravimetric method was used to measure soil moisture, while EC and pH values in the soil: water ratio was measured with pH and EC meter. Soil organic-C was measured with the method of wet oxidation. A modified BaCl$_2$ and MgCl$_2$ method were used to determine soil cations exchange capacity (CEC). Sodium adsorption ratio (SAR) determination was carried out using a wet oxidation method as described in [16]. The contents of exchangeable ion in 1:5 soil: water extracts (cations: Na$^+$, Mg$^{2+}$ and Ca$^{2+}$) were determined by atomic absorption, while anion (Cl$^-$) was measured by a set of ion chromatography equipment.

Observation data of growth parameters were obtained from the samples plant includes height, stems number and shoot weight at 12 WA. Parameters of spears yield quality was determined from the number, fresh weight and especially grade of each asparagus spears according to generally accepted criteria [17].

2.4. Statistical analysis
Analysis of the collected data used SPSS v.17 [18] and the significance of the mean values determined by using the Duncan Test (DMRT) at P ≤ 0.05. The interaction of the main effects of NaCl concentrations and asparagus cultivars was tested by two-way variance analysis.

3. Results
Initial analysis of soil used in this study was classified as Inceptisols, indicated by its low percentage of base saturation (38.32 %), slightly acidic (pH 6.70), low contents of total N and organic-C (0.20% and 1.65%, respectively) (Table 1).

No interaction between NaCl concentrations and asparagus cultivars affected soil physical properties at 12 WAP (Table 2). The contents of soil water and organic-C were not affected by the concentrations of NaCl and different asparagus cultivars. However, the enhancement of soil EC (1.04 - 1.58 dS m$^{-1}$) were significantly caused due to the application of higher NaCl concentrations compared to the initial soil EC (1.10 dS m$^{-1}$).
Table 1. Initial soil properties in the medium elevation of Jatinangor.

| Parameter                                | Values | Criteria* |
|------------------------------------------|--------|-----------|
| pH H₂O                                   | 6.70   | slightly acidic |
| Total N (%)                              | 0.20   | low       |
| Organic-C (%)                            | 1.65   | low       |
| C/N                                      | 8.00   | low       |
| Available P (mg kg⁻¹)                    | 14.67  | high      |
| Cation Exchange Capacity (CEC, cmol kg⁻¹)| 14.35  | low       |
| Exchangeable Cations (cmol kg⁻¹):         |        |           |
| K⁺                                       | 0.15   | low       |
| Na⁺                                      | 0.40   | moderate  |
| Ca²⁺                                     | 5.40   | moderate  |
| Mg²⁺                                     | 2.79   | moderate  |
| Al³⁺                                     | 0.31   | very low  |
| H⁺                                       | 0.48   | low       |
| Sodium Adsorption Ratio (SAR)            | 0.20   | low       |
| Base saturation (%)                      | 38.32  | low       |
| Electrical Conductivity (EC, dS m⁻¹)     | 1.10   | low       |
| Cl⁻ (mg kg⁻¹)                            | 15.86  | low       |
| Texture:                                 |        | sandy clay |
| Sand (%)                                 | 36     |           |
| Silt (%)                                 | 10     |           |
| Clay (%)                                 | 54     |           |

* Soil criteria from Indonesian Soil Center Research (1982)

Table 2. Soil physical properties due to the application of NaCl concentrations planted by five asparagus cultivars at 12 WAP.

| Treatments                  | Water content (%) | Org-C (%) | EC (dS m⁻¹) |
|-----------------------------|-------------------|-----------|-------------|
| NaCl concentrations (g L⁻¹) |                   |           |             |
| 1                           | 27.3ᵃ              | 2.74ᵃ     | 2.14ᵃ       |
| 2                           | 26.2ᵃ              | 2.66ᵃ     | 2.40ᵇ       |
| 3                           | 26.6ᵃ              | 2.52ᵃ     | 2.68ᵇ       |
| Cultivars:                  |                   |           |             |
| Atlas F1                    | 27.4ᵃ              | 2.81ᵃ     | 1.78ᵃ       |
| de Paoli                    | 27.3ᵃ              | 2.62ᵃ     | 2.14ᵃ       |
| Jing Green                  | 26.7ᵃ              | 2.50ᵃ     | 2.18ᵃ       |
| San knight                  | 26.9ᵃ              | 2.62ᵃ     | 2.00ᵃ       |
| Jaleo                       | 25.3ᵃ              | 2.64ᵃ     | 1.99ᵃ       |

According to DMRT at (P ≤ 0.05) mean values with different letters are statistically significant; ns: non-significant; EC: electrical conductivity; WAP: weeks after planting

Interaction of the treatments on soil chemical properties at 12 WAP was not found (Table 3). Application of NaCl concentrations did not significantly affect soil pH and CEC, although the average soil pH values decreased sharply than the soil pH value before any treatments (6.70). However, higher NaCl concentrations significantly influenced the levels of Na⁺ and Cl⁻ in the soil and caused higher SAR values. Meanwhile, the concentrations of Ca²⁺ and Mg²⁺ were significantly lower due to the higher application of NaCl concentrations. The enhancement soil Na⁺ concentration (1.77-2.34 cmol kg⁻¹) due to the applications of NaCl significantly reduced the levels of Ca²⁺ and Mg²⁺ in the soil, respectively by 1.23 cmol kg⁻¹ and 1.44 cmol kg⁻¹.
Table 3. Soil chemical properties due to the application of NaCl concentrations planted by five asparagus cultivars at 12 WAP.

| Treatments                  | pH (H₂O) | CEC | Na⁺ | Ca²⁺ | Mg²⁺ | SAR | Cl⁻ |
|----------------------------|----------|-----|-----|------|------|-----|-----|
| NaCl concentrations (g L⁻¹) |          |     |     |      |      |     |     |
| 1                          | 4.6ᵃ     | 16.4ᵃ | 1.94ᵇ | 3.25ᵇ | 2.43ᵇ | 1.15ᵃ | 25.02ᵃ |
| 2                          | 4.8ᵃ     | 16.02ᵃ | 1.77ᵃ | 3.14ᵇ | 1.15ᵇ | 1.20ᵇ | 26.62ᵇ |
| 3                          | 4.7ᵃ     | 16.03ᵃ | 2.34ᵇ | 2.02ᵃ | 0.99ᵃ | 1.91ᵇ | 27.79ᵇ |
| Cultivars:                  |          |     |     |      |      |     |     |
| Atlas F1                   |          |     |     |      |      |     |     |
| de Paoli                   | 5.0ᵃ     | 16.62ᵃ | 1.42ᵃ | 3.16ᵃ | 1.05ᵃ | 0.98ᵃ | 20.23ᵃ |
| Jing Green                 | 4.8ᵇ     | 15.98ᵇ | 1.16ᵇ | 3.07ᵇ | 3.15ᵇ | 1.19ᵇ | 21.35ᵇ |
| San knight                 | 4.6ᵇ     | 16.23ᵇ | 1.37ᵇ | 3.15ᵇ | 3.15ᵇ | 1.19ᵇ | 21.49ᵇ |
| Jaleo                      | 4.5ᵃ     | 16.17ᵃ | 1.67ᵃ | 3.19ᵃ | 0.89ᵃ | 1.17ᵃ | 23.79ᵃ |

According to DMRT at (P ≤ 0.05) mean values with different letters are statistically significant; ns: non-significant; CEC: cation exchange capacity; SAR: Sodium Adsorption Ratio; WAP: weeks after planting

Throughout the twelve weeks of the experiment, the growth response of five asparagus cultivars in all NaCl treatments showed symptomless of soil-borne attack. The interaction between NaCl concentrations and asparagus cultivars was not found to influence plant height, stem number, shoot weight and spears yield quality of asparagus cultivars at 12 WAP (Table 4).

The effect of NaCl and differences in cultivar on the asparagus spears yield was observed by calculating and weighing the number and weight of fresh spears as well as being classified as Grade A, B and C after twelve weeks of cultivation. The results showed although NaCl concentrations had no significant effect on plant growth components, the cultivars had a great influence on the numbers, weight and grades of asparagus spears (P < 0.05). Among the cultivars tested, a significantly higher percentage of marketable spears numbers (54.3%) and weights (66.4%) produced by asparagus cultivar of Jaleo; while cultivar of Atlas F1 resulted in 50.9% and 62.6% respectively. Compared with the other three cultivars which the diameter lower than 0.6 cm (grade C), Jaleo and Atlas F1 had a spear lengths approximately 25 cm and diameter ranged from 0.6 – 1.5 cm (grade A – B).

Table 4. Growth components and spears yield quality of five asparagus cultivars influenced by NaCl concentrations at 12 WAP.

| Treatments                  | Plant height (cm) | Stem number | Shoot weight (kg plot⁻¹) | Spears number (%) | Spears weight (%) |
|----------------------------|-------------------|-------------|----------------------------|-------------------|-------------------|
| NaCl concentrations (g L⁻¹) |                   |             |                            |                   |                   |
| 1                          | 170.0ᵃ             | 17.5ᵃ       | 6.9ᵃ                       | 37.2ᵃ             | 62.8ᵃ             | 52.9ᵃ             | 47.1ᵃ             |
| 2                          | 171.2ᵃ             | 19.2ᵃ       | 6.9ᵃ                       | 38.9ᵃ             | 61.1ᵃ             | 58.5ᵃ             | 41.4ᵃ             |
| 3                          | 167.6ᵃ             | 18.6ᵃ       | 6.6ᵃ                       | 40.1ᵃ             | 59.9ᵃ             | 61.2ᵃ             | 38.8ᵃ             |
| Cultivars:                  |                   |             |                            |                   |                   |                   |                   |
| Atlas F1                   | 176.9ᵃ             | 19.2ᵃ       | 9.0ᵃ                       | 50.9ᵇ             | 49.1ᵃ             | 62.6ᵇ             | 37.4ᵃ             |
| de Paoli                   | 171.1ᵃ             | 18.1ᵃ       | 6.7ᵃ                       | 42.1ᵃ             | 57.9ᵃ             | 57.1ᵇ             | 42.8ᵃ             |
| Jing Green                 | 165.3ᵃ             | 15.2ᵃ       | 6.9ᵃ                       | 43.6ᵃ             | 52.4ᵃ             | 59.3ᵃ             | 40.7ᵃ             |
| San knight                 | 163.7ᵃ             | 17.6ᵃ       | 5.0ᵃ                       | 42.4ᵃ             | 57.6ᵃ             | 52.5ᵃ             | 47.5ᵃ             |
| Jaleo                      | 171.0ᵃ             | 21.2ᵇ       | 10.1ᵇ                      | 54.3ᵇ             | 55.7ᵃ             | 66.4ᵇ             | 33.6ᵇ             |

According to DMRT at (P ≤ 0.05) mean values with different letters are statistically significant; ns: non-significant; WAP: weeks after planting; ¹*: marketable spears (grade A - B); ²*: unmarketable spears (grade C).
4. Discussion

Analyses of soil particle size distribution from the tillage layer (0-30 cm) indicated that the soil properties used in this experiment were sandy clay with a low capacity to exchange cations (CEC) and base saturation, while Al concentration was low (Table 1). The high clay content in the soil (54%) had the potential to increase the adsorption surface area and resulted in the increased of Hydrogen ion content (low pH). This indicated also that low soil pH could affect the level of soil EC (Table 2). [19] confirmed that the EC of a soil solution increased with the increased concentration of ions (Table 3). This meant that the range of soil pH (4.5–5.0) due to NaCl applications in this study significantly increased soluble salt content in the soil, although the EC value of soil also depending on the amount of moisture held by soil particles [20].

Supported for the statement, [21] reported that soil pH influenced the soil EC indirectly, although it was possible to affect the solubility of NaCl and soil water content because soil EC had a direct relationship with salinity. [22] found that alkaline soil contained less dissolved salt so that lower soil pH would cause higher dissolved salt and increase soil EC. Even at the same molar concentration [23] revealed that NaCl application into the soil has more effect on pH value rather than KCl.

The expulsion of Ca and Mg into soil solutions occurred through the exchange of ions within soil particles, due to the presence of Na in a large quantity (Table 3), as well as decreasing soil pH due to loss of Ca\(^{2+}\) ion. This indicated that the ratio of Na\(^{+}\) and combination of Ca\(^{2+}\) and Mg\(^{2+}\) concentrations in the soil that expressed the balance of both components was managed by soil ions, water content and the levels of salinity in the soil [24].

It is well understood that a rise in NaCl concentration will increase the activity of ions due to the high degree of dissociation of the salt. According to [25] the absorption of interacting antagonistic anions has important meaning because the concentration of Cl\(^{-}\) in the soil solution can be rather high under conditions of NaCl salinity. On the contrary, properties of Cl\(^{-}\) did not adsorb by the surface of soil particles and moved readily with the water due to its mobility in the soil so the presumption of [26] about the presence of Cl\(^{-}\) in the soil and its implication for the plant can be detrimental is unreasonable. Also, the presence of irrigation, rainfall and evapotranspiration is mainly related to the fluxes of water within the soil which determines the movement of Cl. Physiological processes that take place in the plant depend on the presence of chloride-based salt so that the indirect effect of positive or negative is reflected by the resistance of the plant to external stress, pest or disease attacks [27]. Results of growth components and spears yield quality (Table 4) showed that the growth response of five asparagus cultivars in all NaCl treatments showed symptomless of soil-borne attack throughout the twelve weeks.

[28] stated that NaCl influenced the osmotic pressure so that variations in plant sensitivity were influenced by water holding capacity and water content of the soil. No significantly different in plant height, stem number and shoot weight of all asparagus cultivars to NaCl applications were caused by the high ability of asparagus as a perennial plant’s group to tolerate high levels of soil salinity [29]. This study also supported the results of [30] and [31] that asparagus is proven to be one of the vegetable plants that are tolerant of the salt content in the growing media. From various concentrations of NaCl and different asparagus cultivars, it could be shown that all cultivars are found to tolerate a concentration as high as 3000 ppm of total salt. Thus, it seemed that differences in salt tolerance occur with genetic traits as evidenced by [32] that when the soil salinity exceeds the plant-specific threshold, then the yield will automatically decrease.

Since asparagus yield highly determined by the number of photosynthates which was stored in the underground crown of the plant [33], the low availability of Ca\(^{2+}\) and Mg\(^{2+}\) concentrations in the soil (Table 3) as a consequence of the high presence of soil Na\(^{+}\) ion potentially contributed to the variations in spears yield quality of asparagus cultivars (Table 4). Grading spear quality of asparagus influenced the marketable yields of spears so that higher marketable spears numbers and fresh weight (grade A-B) were significantly produced by Jaleo and Atlas F1 cultivars compared to the others. These results are in line with the statements of [34] that Jaleo cultivar was able to adapt to warm climates and had a genetic relationship with Atlas F1 cultivar. Moreover, the cultivar of Atlas F1 had a high tolerance to diseases caused by *Fusarium sp* and leaf rust by *Cercospora sp*. The reasons why the number and weight of asparagus spears yield higher than the others, it could be supported by the results of [35] and
[36] who reported that the adaptability of plants to grow in a high salinity environment is related to differences in the mechanism of tolerance to salinity so that it is classified as a salt-tolerant plant (Halophyte). Overall, it is notable that all cultivars could acclimatize with the growing environment.

5. Conclusion

This study revealed that the addition of NaCl as ameliorant into the soil caused the increase of Na⁺, Cl⁻ concentrations and SAR values, but decreased the concentrations of Ca²⁺ and Mg²⁺. The application of NaCl was able to anticipate the soil-borne attacks and support the growth of five asparagus cultivars in the tropical areas. Our finding showed that two asparagus cultivars of Jaleo and Atlas F1 possibly supported by its genetic traits and the ability to acclimatize the environmental conditions so had the potential to be cultivated in the medium elevation of tropical areas. The use of high potential cultivars will help farmers to cultivate and produce high-quality asparagus products so that consumer demand can be fulfilled.

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