Drought stress and K effects on contents of soil water and organic matter, CEC, exchangeable-K, yield and water productivity of sweet corn on Inceptisols

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Abstract. The research was conducted to study the effects of drought stress and K fertilizer on plant growth, contents of soil water (SWC) and organic matter (SOM), cation exchange capacity (CEC), K-exchange, yield and water productivity of sweet corn (Zea mays saccharata Sturt) grown in Inceptisols. The research was conducted on a plastic house in a controlled culture experiment field, Faculty of Agriculture, Universitas Padjadjaran using a factorial randomized block design (RBD). The first factor was the four percentages of drought stress (0%, 20%, 40% and 60%). The second factor was three levels of KCl dose (1, 1.25 and 1.50 times the recommended dose of 50 kg ha⁻¹ KCl). The treatment combinations were repeated three times. The interaction between 20-40% drought stress and 1.50 times dose of KCl had a significant effect on stem diameter and independently this KCl dose affected the leaf numbers, but without drought stress. The treatment without drought stress resulted in highest plant height and leaf area index, while drought stress of 40-60% gave higher SOM and CEC, even in 60% drought stress showed a higher exchangeable K. The application of 1.25 times dose of KCl caused higher K-uptake, while the treatment of 40% drought stress gave higher water productivity.

1. Introduction
In Indonesia sweet corn (Zea mays saccharata Sturt L.) has developed as a type of young harvested plant that is widely cultivated in the tropical low land. However, the productivity of sweet corn in Indonesia is still relatively lower compared to other tropical countries like Brazil [1] due to the cultivation system which is constrained by environmental factors. Uneven rainfall combined with increasing global temperatures has caused a lack of water availability in dryland farming to be a limiting factor for growth. As a consequent, drastically reduced crop production is occurred by low soil productivity. Highlighting the role of water and fertilizer management for sustainable agriculture therefore must be of particular concern.

Among all the environmental factors, drought is the most important environmental factor which affected growth and development of plants [2]. The availability of plant nutrients which are closely related to soil water content indicates that water is a very influential factor [3]. Therefore, in terrestrial
ecosystems, poor plant growth during the severe dry season still can be nourished when soil moisture increases due to water content fluctuations in the soil. Thus, water is a key driver of several ecosystems functions, including biomass and crop yields.

Several studies have shown that the detrimental effects of drought can be mediated by applying a slightly excessive dose of nutrients to mediate this adverse effect, thereby improve drought resistance of plants [4]. As one of the essential macronutrients, Potassium (K) has the potential to develop plant resistance to drought. When K supply is limited, plant growth will be disrupted, especially when there is high light intensity accompanied by the appearance of leaf chlorosis and necrosis. In conditions of minimal soil moisture, K is assumed to play an important role in the plant metabolism process, the regulation of guard cells, flow of water, nutrients, and carbohydrates within the plants, where the opening or closing of stomata depends on the availability of mesophyll water [5]. Therefore, this study aimed to observe the effects of drought stress combined with the application of various doses of KCl on plant growth components, soil physicochemical properties, yield and water productivity of sweet corn (Zea mays saccharata Sturt), as well as to know the relationship between net use of consumptive water in increasing the productivity of sweet corn under various drought stress conditions.

2. Methods
2.1. Experiment site
The research was done under a plastic house at the controlled culture experimental field, Faculty of Agriculture Universitas Padjadjaran used factorial Randomized Block Design (RBD). The first factor was the percentage of drought stress which comprised four levels (0%, 20%, 40% and 60% of drought stress), which were equivalent to 100% of soil water availability (SWA) and considered as a control, followed by 80%, 60% and 40%. The second factor was the KCl dose comprised three levels (1, 1.25 and 1.50 times the recommended dose of 50 kg ha\(^{-1}\) KCl). The treatment combinations were repeated three times.

The soil was derived from the area around the experimental field. Each polybag containing 37 kg of soil was planted with one seed of sweet corn variety Bonanza F-1 and prepared for the observation of growth parameters in the vegetative and generative stages. The basal rate of compost at 10 t ha\(^{-1}\) and recommended doses of N, P fertilizers (300 kg ha\(^{-1}\) Urea and 150 kg ha\(^{-1}\) SP-36, respectively) were mixed with the soil before planting.

To support the plant growth, the difference between field capacity and the wilting point was considered as the amount of soil water availability (SWA). The Gravimetric method was used before daily irrigation was done by giving an amount of water into each polybag. The amount of water supplied is measured using a cylinder and beaker glass. The formula for water supply was as follow:

\[
Irrigation\ water\ (L) = \frac{W_{fc}-W}{\rho w} - 1F\]

where \(W_{fc}\) = soil weight in each polybag (kg) at field capacity; \(W\) = weight of soil before watering (kg); \(\rho w\) = density of water used (1.0 kg L\(^{-1}\)); 1F = the fraction of leaching (IF = 0.20) [6].

To measure the index of leaf area the method used was as follows [7]:

\[
A = KL B\]

where \(A\) = area of leaf (cm\(^2\)), \(L\) = length of leaf (cm), \(B\) = breath at mid-point, \(K\) = factor of reduction for the plant under observation. Along the plant growth stages, the maximum evapotranspiration (ETm) was calculated by the modified equations of [8] and [9]:

\[
ET_m = K_c \cdot F_c\]

where \(ET_m\) = maximum evapotranspiration of the plant (mm), \(K_c\) = coefficient of consumptive plant use, \(F_c\) = factor of consumptive use which recapitulated from the Hygrothermograph tool and meteorological data. Along the plant growth stages, the net consumptive water use was recorded and related to the mean number of days after planting. The suitability of plant growth phases was calculated by multiplying the

2
period of net consumptive use by the number of days along with the plant growth. To record crop production, water productivity (WP) is calculated from the net amount of water consumed by sweet corn plants per gram of yield in each polybag. The WP was calculated from the total water applied to each treatment (L polybag⁻¹) and the weight of total yield (g plant⁻¹) as shown by [11]:

\[ WP (L \text{ g}^{-1} \text{ polybag}^{-1}) = \frac{\text{Total water applied (L polybag}^{-1})}{\text{Yield (g plant}^{-1})} \]  \hspace{1cm} (4)

2.2. Laboratory analysis

Plant and soil sampling was carried out at the end of the vegetative stages (56 DAS). Soil physicochemical properties were analysed in the laboratory after the soil sample was air-dried and sieved with a size of 2 mm. Different methods adopted for soil properties determinations are listed in Table 1. To calculate the percentage of SOM from organic C used the conversion factor of 1.72 [10].

2.3. Statistical analysis

Data analysis was performed using statistical software packages SPSS v 27.0 and Microsoft Office Excel 2019. Fisher's test at 5% probability [12] was used to determine the mean value with the least significant difference. To determine the relationship between total water supply and crop water production used correlation analysis and significance was tested at 5% probability.

3. Results

3.1. Soil physicochemical characteristics

Initial analysis of soil used in this study was classified as Inceptisols which characterized by the high percentage of clay content (67 %), acidic soil pH (5.40), low contents of total N, available P and exchangeable K⁺ (0.20%, 5.61 mg kg⁻¹, 0.22 cmol kg⁻¹ respectively) (Table 1). Average daily temperature and relative humidity in the plastic house during the experiment ranged between 24.4 -36.9 °C and 43.0 – 75.5%, respectively.

| Parameter and Analysis methods | Values          | *Criteria[13] |
|--------------------------------|-----------------|---------------|
| pH H₂O (Potentiometric)        | 5.40            | acidic        |
| Total N Kjeldahl [14]          | 0.20%           | low           |
| Organic-C [15]                 | 2.73%           | medium        |
| C/N                            | 16              | high          |
| Available P [16]               | 5.61 mg kg⁻¹    | low           |
| Cation Exchange Capacity: [17] | 17.37 cmol kg⁻¹ | medium        |
| K⁺                             | 0.22 cmol kg⁻¹  | low           |
| Na⁺                            | 0.05 cmol kg⁻¹  | very low      |
| Ca²⁺                           | 7.66 cmol kg⁻¹  | medium        |
| Mg²⁺                           | 3.35 cmol kg⁻¹  | high          |
| Base saturation                | 34.14%          | medium        |
| Al³⁺                           | 0.13 cmol kg⁻¹  | very low      |
| H⁺                             | 0.07 cmol kg⁻¹  | low           |
| Texture [18]                   |                 |               |
| Sand (%)                       | 10              |               |
| Silt (%)                       | 23              |               |
| Clay (%)                       | 67              | clay          |
Interaction between 20-40% drought stress and the application of 1.50 times the recommended dose of KCl at 28 DAP significantly resulted in the highest stem diameter of sweet corn compared to other treatments (Table 2). However, in conditions without drought stress (100% SWA) the application of 1 time recommended dose of KCl produced the highest number of sweet corn leaves.

Table 2. Interaction between drought stress and KCl combination on stem diameter and leaves number of sweet corn at vegetative stage (28 DAP*)

| Treatments                  | Dose of KCl | Dose of KCl |
|-----------------------------|-------------|-------------|
|                            | k1          | k2          | k3          | k1          | k2          | k3          |
| w1: 0% drought stress (100% SWA) | 1.47 a       | 1.04 a       | 1.44 b       | 7.33 b       | 6.83 a       | 6.67 a       |
| w2: 20% drought stress (80% SWA) | A           | A           | A           | A           | A           |
| w3: 40% drought stress (60% SWA) | 1.07 a       | 1.01 a       | 1.61 b       | 6.33 a       | 6.50 a       | 6.70 a       |
| w4: 60% drought stress (40% SWA) | 1.18 a       | 1.44 c       | 1.49 b       | 6.00 a       | 6.31 a       | 6.64 a       |
| k1 : 1 time the recommended dose of KCl | A           | A           | A           | A           |
| k2 : 1.25 times the recommended dose of KCl | A           | B           | A           | A           |
| k3 : 1.50 times the recommended dose of KCl | A           | A           | A           | A           |

Based on Duncan's test at α .05, the numbers followed by the same letter are not significantly different. Horizontally (line) = capital letters; vertically (column) = lowercase *DAP: days after planting; SWA: soil water availability; k1: 1 time the recommended dose of KCl; k2: 1.25 times the recommended dose of KCl; k3: 1.50 times the recommended dose of KCl.

The treatment without drought stress (100% SWA) significantly gave higher plant height and leaf area index of sweet corn along the vegetative stages (42-56 DAP) (Table 3). With an increase in the percentage of drought stress (20-60%), it was shown that there was a tendency to decline in the plant height of sweet corn. Meanwhile, the application of various doses of KCl did not affect plant height and leaf area index during the vegetative stage.

Table 3. Effects of drought stress and KCl combination on plant height, and leaf area index of sweet corn along the vegetative stages (42-56 DAP*)

| Treatments                  | Plant height (cm) | Leaf area Index (LAI) |
|-----------------------------|-------------------|-----------------------|
|                            | 42 DAP            | 56 DAP                |
| w1: 0% drought stress (100% SWA) | 135.36 c         | 167.60 c              |
| w2: 20% drought stress (80% SWA) | 112.81 b         | 129.65 b              |
| w3: 40% drought stress (60% SWA) | 105.60 b         | 117.54 b              |
| w4: 60% drought stress (40% SWA) | 85.07 a          | 91.12 a               |
| k1 : 1 time the recommended dose of KCl | 104.83 a         | 120.77 a              |
| k2 : 1.25 time the recommended dose of KCl | 105.44 a         | 126.30 a              |
| k3 : 1.50 time the recommended dose of KCl | 118.81 a         | 132.36 a              |

Based on Duncan's test at α .05, the numbers followed by the same letter are not significantly different. Horizontally (line) = capital letters; vertically (column) = lowercase
Based on Duncan's test at $\alpha = 0.05$, the numbers followed by the same letter are not significantly different. 

Neither the drought stress nor the KCl treatments had a significant effect on the soil water content (SWC) at 56 DAP, however, significantly higher SOM and CEC levels were found in the 40-60% drought stress treatment (Table 4). The high clay content of this soil type (67%, Table 1) together with higher SOM and CEC values was likely to support the higher concentration of exchangeable K, especially in drought stress of 60% (40% SAW). A higher concentration of exchangeable K also resulted due to the application of the 1 time recommended dose of KCl, whereas increasing the recommended dose of KCl (1.25-1.50 times) did not have any significant effect on SOM and CEC values.

Table 4. Effects of drought stress and KCl combination on soil water content, soil organic matter, cation exchange capacity and exchangeable K at 56 DAP*

| Treatments                      | SWC (%) | SOM (%) | CEC (cmol kg$^{-1}$) | Exchangeable-K (cmol kg$^{-1}$) |
|--------------------------------|---------|---------|----------------------|----------------------------------|
| w$_1$: 0% drought stress (100% SWA) | 16.93 a | 4.84 a  | 17.88 a              | 0.36 a                           |
| w$_2$: 20% drought stress (80% SWA) | 16.96 a | 5.14 ab | 18.43 ab             | 0.52 b                           |
| w$_3$: 40% drought stress (60% SWA) | 16.20 a | 5.29 b  | 18.83 b              | 0.54 b                           |
| w$_4$: 60% drought stress (40% SWA) | 15.68 a | 5.30 b  | 18.95 b              | 0.65 c                           |
| k$_1$: 1 time the recommended dose of KCl | 16.59 a | 5.02 a  | 18.50 a              | 0.59 b                           |
| k$_2$: 1.25 time the recommended dose of KCl | 16.40 a | 5.05 a  | 18.17 a              | 0.50 a                           |
| k$_3$: 1.5 time the recommended dose of KCl | 16.33 a | 5.06 a  | 18.90 a              | 0.49 a                           |

Based on Duncan's test at $\alpha = 0.05$, the numbers followed by the same letter are not significantly different. 

*DAP: days after planting; SWA: soil water availability

Independently, the statistical analysis shows that without drought stress (100% SWA) with 84.87 L of net consumptive water use caused significantly higher K-uptake, cobs diameter and total yield weight of sweet corn. However, the higher water productivity (0.47 L$^{-1}$ g$^{-1}$ plant$^{-1}$) was caused by the treatment of 40% drought stress. Application of various recommended dose of KCl did not have any significant effect on yield component and water productivity, except the application of 1.25 times the recommended dose of KCl significantly caused higher K-uptake sweet corn (Table 5). The relationship between total net consumptive water use and crop water productivity of sweet corn is shown in Figure 1.
Table 5. Effects of drought stress and KCl combination on K-uptake, yield component and water productivity of sweet corn at 78 DAP*

| Treatments                                    | Net consumptive water use (L plant⁻¹) | K-uptake (%) | Diameter of corn cobs (cm plant⁻¹) | Total yield weight of sweet corn (g plant⁻¹) | Water productivity (L g⁻¹ plant⁻¹) |
|-----------------------------------------------|---------------------------------------|--------------|------------------------------------|----------------------------------------------|----------------------------------|
| w₁: 0% drought stress (100% SWA)             | 84.87                                 | 1.35 b       | 4.25 c                             | 319.30 c                                     | 0.27 a                           |
| w₂: 20% drought stress (80% SWA)             | 61.62                                 | 1.27 ab      | 4.00 b                             | 211.89 b                                     | 0.29 a                           |
| w₃: 40% drought stress (60% SWA)             | 47.19                                 | 1.20 a       | 3.61 a                             | 100.22 a                                     | 0.47 b                           |
| w₄: 60% drought stress (40% SWA)             | 36.74                                 | 1.14 a       | 2.97 a                             | 83.78 a                                      | 0.44 ab                          |
| k₁: 1 time the recommended dose of KCl       | 54.99                                 | 1.14 a       | 3.55 a                             | 186.25 a                                     | 0.30 a                           |
| k₂: 1.25 times the recommended dose of KCl   | 52.39                                 | 1.36 b       | 3.27 a                             | 181.33 a                                     | 0.29 a                           |
| k₃: 1.50 times the recommended dose of KCl   | 53.48                                 | 1.20 a       | 3.54 a                             | 169.58 a                                     | 0.32 a                           |

Based on Duncan’s test at α .05, the numbers followed by the same letter are not significantly different.

*DAP: days after planting; SWA: soil water availability

Figure 1. Relationship between total net consumptive water use and water productivity of sweet corn

4. Discussion

Environmental conditions in the plastic house and soil physicochemical properties (Table 1) used in this study supported the growth of sweet corn plants. The average daily temperature (24.4-36.9 °C), relative humidity (43.0–75.5%) and light intensities directly above the tallest canopy (11-12 µmol m² s) were found to be adequate for vigorous plant growth [19].
Interaction between drought stress (20-40%) and K fertilizer (1.50 times the recommended dose) at 28 DAP (Table 2) indicated that higher supply of K at soil water availability of 60-80% could support the development of stem diameter due to K function in strengthening the plant cell walls, although the early stage of sweet corn seedling growth was very sensitive to drought. According to [20] the status of water in plants greatly affected stem diameter and if the water supply by the roots was lower than the transpiration from the leaves, the stem diameter can be reduced due to water pressure. This indicates that in supporting maximum plant growth, optimal soil water availability at the vegetative stages must be fulfilled.

The results of this study also revealed that the values of plant height and leaf area index of sweet corn in the vegetative phase were higher (Table 3) due to the treatment without drought stress (100% SWA). In accordance with plant development, water requirements along the growing period of sweet corn were very different, although at the vegetative stage the plant was relatively tolerant of water stress, but very sensitive in the generative phase [21]. It was known that water is used by plants for cell division and enlargement, which was manifested in an increase in plant height and leaf propagation [22]. [23] and [24] stated that decreasing plant canopy during drought caused a decrease in plant water loss, while a decrease in plant height, diameter and weight of sweet corn cobs as a result of stomata closure and high stomatal resistance. Therefore, the barriers to stem elongation, increase in stem diameter and the formation of new leaves (Table 2) and leaf area under drought stress treatment (Table 3) was mainly due to a decrease in plant water content as an inhibitor of plant growth.

According to [25] the number and average leaf area of plants were reduced due to drought stress, which reduced the total leaf area of a plant because enlargement of the leaf size depends on leaf turgidity, temperature and assimilate supply for growth. This study supposed that the lack of water supply at the vegetative growth stage made the leaf area index of sweet corn smaller as mentioned by [26] that when the water content of the plant was limited, less carbon was utilized during the growing period of the plant. The application of various KCl doses did not affect plant height and leaf area index at all presumably because K+ which was absorbed from the soil will be distributed evenly to all plant organs of sweet corn. Furthermore, [27] found that the distributed K+ was then converted through metabolic processes in plants to become seeds and husks of sweet corn.

Higher SOM content and CEC levels in the drought stress treatment of 40-60% (Table 4) indicated that the high content of clay in the soil (Table 1) played an important role in maintaining the soil water capacity. [28] mention that fine-textured soil will have a larger amount of surface area and will hold more water as well as cations due to the negative charge on the clay surface. According to [29] soil organic matter played an important role to improve CEC of soils. Lower SOM content in the treatment without drought stress has been recognized as an ineffective condition of improving soil physicochemical conditions, as well as water-holding capacity. It means that the contents of clay and organic matter in this soil studied can be a good indication to assess the soil concentration of exchangeable K in terms of support for plant growth. Meanwhile, the application of 1 time recommended dose of KCl resulted in a higher exchangeable K. It was known that K which came from fertilizer would move to saturate the adsorption complex so that equilibrium with K in the soil solution was achieved [30]. The major contribution of K+ on CEC might be the cause of a directly proportional relationship between soil organic matter and extractable- K.

The treatment without drought stress (100% SWA) with the amount of 84.87 L of consumptive water resulted in higher K-uptake, cob diameter, and total yield weight of sweet corn significantly (Table 5). Although plant height decreased due to 20-60% drought stress (Table 3), this study found that the cob diameter and yield weight of sweet corn only decreased under severe drought stress (40-60%) compared to without drought stress (100% SWA, Table 5). Surprisingly, the higher water productivity (0.47 L\textsuperscript{-1} g\textsuperscript{-1} plant\textsuperscript{-1}) was found due to the treatment of 40% drought stress. This shows that the optimal level of soil water availability at the vegetative stage played an important role in supporting maximum growth continuously. On the other hand, the application of various recommended doses of KCl did not significantly affect the yield component, but the uptake of K wa significantly affected due to the application of 1.25 times of KCl (Table 5). According to [31] the availability of water in the soil greatly
determined the absorption and transportation of K\textsuperscript{+} from the soil to the plant and was involved in various processes of cell regulation, stomatal movement and water transportation [32].

5. Conclusion
The results of this study concluded that plant water productivity (WP) and drought tolerance could be improved through genetic engineering and cultivation techniques (for example, balanced fertilization) so that water use could be utilized effectively and efficiently. There is a relationship between moderate levels of productivity and high yields in the effectiveness of water use.

6. References
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