Characteristics of root growth and soybean yield on drought stress

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Abstract. Drought stress is a major limiting factor for soybean cultivated on dry land. Water limitation in the root zone will inhibit the growth, development and yield of soybeans. This research aimed to study the characteristics of root growth and its effect on soybean yield on drought stress. The study used a pot method with two levels of treatment, 80% field capacity (FC) and 20% FC. Tested indicator plants were soybean consisting of two types, namely Nanti and Cikuray. The results showed that the Nanti Variety at 20% FC groundwater content experienced a percentage decrease in root dry weight, root volume, root length, shoot dry weight, and dry seed yield with the values of 58.33; 73.2; 24.85; 69.63 and 73.00%, respectively. Cikuray varieties experienced a decrease in root dry weight (55.17%), root volume (43.8%), root length (47.13%), shoot dry weight (71.05%), and dry seed yield (62.78%), respectively.

1. Introduction
Environmental factors in this case drought in plants is one of the major obstacles for the growth and development of a plant. Drought can have a significant effect and its effects can be permanent if it is not dealt immediately. Lack of water internally in plants results directly in decreased cell division and enlargement. In the vegetative growth stage, water is used by plants for cell division and enlargement which is manifested in plant height increase, diameter enlargement, leaf propagation, and root growth. Water stress causes a decrease in turgor in plant cells and results in decreased physiological process.

This drought stress is a major obstacle to plant growth and productivity on dry land [1]. At present, drought is the most damaging major stress affecting the greatest decline in agricultural output. Most of the cultivated plants are comparative and susceptible to water shortages. Water scarcity may become worse in the future with global climate change. Lack of sufficient moisture causing drought stress is a common phenomenon in dry land, which is caused by rare rain and poor irrigation [2]. Reduction of economic results due to drought stress at various stages of growth has been reported on soybeans [3], corn [1], barley [4], rice [5], beans [6], and potatoes [7].

Several studies show that each type of plant will develop its root system on drought stress. The development of root systems is one of the mechanisms of plants on drought stress demonstrating the level of tolerance of plants to drought stress. The root system plays an important role in drought condition. The nature and level of root characteristics are considered as the main factors influencing the plant's response to drought.
Root length and volume are often used to characterize the development of the root system to see the plant’s response to water stress. Rooting system is also an important indicator of water absorption potential. Thick roots and the number of roots in each sampling can also provide drought tolerance because branching is directly related to the character. Because plants get their water and mineral needs from their roots and the availability of these resources is often a limiting factor for crop productivity. Root development, in essence, is a response to some stresses, especially drought and nutrient deficiency. The ownership of a deep and thick root system allowing plants to access deeper water access to underground, which can be used as an indicator of plants in determining drought tolerance.

The high density of root tissue mass is generally related to the characteristics of environment-seized species, roots of such species tend to have thick cell walls and sclerenchyma. Stress of nutrient availability has been shown to cause an increase in root mass density in a species. However, found that there were several species experiencing a decrease in root tissue mass density in response to stress deficiency in phosphorus.

2. Materials and method
The study was conducted in a plastic house by planting soybeans in a polybag without holes with a size of 30x30 cm. The research aimed to study the pattern of changes in the growth of soybean roots treated with drought stress. The study used a factorial randomized block design with two factors. The first factor was soybean varieties, namely Narti and Cikuray. The second factor was drought stress with water level according to the calculation, which was 20% FC = 38 cc per polybag and 80% FC = 153 cc. Groundwater content was maintained due to the treatments during the study with the gravimetric method. Observation of root growth was carried out during the final vegetative growth phase (four weeks after planting).

3. Results and discussion
3.1. Dry root weight
Dry root weight is an illustration of root growth. Calculation of root dry weight is important, this parameter is used to see the condition of plant metabolism. The increase in root dry weight reflects the accumulation of organic compounds that plants have successfully synthesized from inorganic compounds.

The results of statistical analysis showed that the treatment of drought stress and soybean varieties had each significant effect while the interactions of the two treatments did not significantly affect the root dry weight parameters (Table 1). The response of plants to drought stress is very dependent on the genetic of plants. Cikuray was better able to withstand stress compared to Nanti. Although the development of soybean roots is greatly influenced by the physical and chemical conditions of the soil, soil type, cultivate land procedure, adequacy of nutrients, and availability of water in the soil, but genetic factor determines the success of adapting to its environment.

| Variety | Water content 20% FC | Water content 80% FC | Water content Average | Percentage of decreasing |
|---------|----------------------|----------------------|-----------------------|-------------------------|
| Nanti   | 0.10                 | 0.24                 | 0.17b                 | 58.33                   |
| Cikuray | 0.13                 | 0.29                 | 0.21a                 | 55.17                   |
| Average | 0.12b                | 0.26a                | 0.19                  |                         |

Note: The numbers followed by the same letter in the same row or column are not significant effect according to Duncan's multiple range test at 5% level

The results in Table 1 show the percentage of reduction in root dry weight of Later variety is greater than that of Cikuray. Genetic variation in the ability of soybeans to deal with drought stress
have also been reported by Shaheen et al. [8]. Several studies have shown that the nature of roots has the potential to show the potential of soybean ability to deal with drought stress [9] added a root system that is much deeper from drought-tolerant coffee clones allowing the plant to get more water access. In addition, plants also have the ability to maintain a better internal water status than clones that are prone to drought.

3.2. Root volume

Root volume is a description of the plant roots distribution showing the ability of plants to extract soil. The treatment of drought stress resulted in a decrease in the volume of soybean roots. The decrease depended on the variety (Table 2).

**Table 2. Volume of soybean roots in drought stress**

| Variety | Groundwater content | Percentage of decreasing |
|---------|---------------------|-------------------------|
|         | 20% FC | 80% FC | Average | ml |          |
| Nanti   | 1.08   | 4.03   | 2.56    | 73.2 |
| Cikuray | 2.23   | 3.97   | 3.10    | 43.8 |
| Average | 1.66b  | 4.00a  | 2.83    |      |

Note: The numbers followed by the same letter in the same row or column are not significantly different according to Duncan's multiple range test at 5% level.

Plant root system generally reveals a strong relationship between the area or diameter of the root cross-section, biomass dry weight, and root volume that are derived from a single growing point. There is a close relationship with these three root parameters. The limitation of biomass for root growth as a result of drought stress results in lower root volume. The ability of roots to extract the soil is also low, this certainly affects to low nutrients and water.

3.3. Root length

The treatment of drought stress decreases the length of soybean roots, while the response in each variety is different, although it is statistically not significant. Root length is a character demonstrating the ability of plant roots to gain water. In general, the increasing of stress will elevate root length in plants. However, the results in Table 3 show 20% FC soil water content contributes to a decrease in root length. These results indicate that the drought stress is quite heavy, so the plant is unable to maintain the root cells from the decreasing of soil water content.

**Table 3. Length of soybean roots in drought stress**

| Variety | Groundwater content | Percentage of decreasing |
|---------|---------------------|-------------------------|
|         | 20% FC | 80% FC | Average | cm |          |
| Nanti   | 19.18  | 26.35  | 22.77   | 24.85 |
| Cikuray | 18.57  | 35.13  | 26.85   | 47.13 |
| Average | 18.88b | 30.74a | 24.81   |      |

Note: The numbers followed by the same letter in the same row or column are not significantly different according to Duncan's multiple range test (DMRT) at 5% level.

In general, the size, morphology and architecture of the root system will determine the ability of plants to obtain water and nutrients [10] and influence the relative size and growth rate of shoot [11]. Optimal root system can ensure optimal shoot growth and development because they function as a link between plants and soil. It is known that the root system is more beneficial for plants to obtain water and nutrients. In addition, root length is an indicator of plants ability to absorb water from deeper soil.
layers [12]. However, recent research shows that species with small root system may be more effective than other species with larger root system [13].

The results of the study in Table 4 show that the condition of the groundwater content of 20% FC can only provide 0.62g crown growth, whereas at 80% FC the crown dry weight reaches 2.09 g.

Table 4. Soot dry weight of soybean on drought stress treatment

| Variety | Groundwater content | Percentage of decreasing |
|---------|---------------------|-------------------------|
|         | 20% FC | 80% FC | Average |                      |
| Nanti   | 0.58  | 1.91  | 1.24    | 69.63               |
| Cikuray | 0.66  | 2.28  | 1.27    | 71.05               |
| Average | 0.62b | 2.09a | 1.36    |                      |

Note: The numbers followed by the same letter in the same row or column are not significantly affect according to Duncan's multiple range test (DMRT) at 5% level

The growth of depressed shoot is limited by the ability of root to extract water from the soil and move it to the shoot plant. Although roots may appear to be the most susceptible parts of plants (because of their exposure to stress water shortages), the response intensity of the root system can vary according to species, level and duration of stress and cultivation conditions. A decrease in groundwater level from 80% to 20% FC results in a decrease in root and shoot growth, which also contributes to the decline of plant seed weight (Table 5).

Table 5. Shoot dry weight of seeds per plant on drought stress

| Variety | Groundwater content | Percentage of decreasing |
|---------|---------------------|-------------------------|
|         | 20% FC | 80% FC | Average |                      |
| Nanti   | 0.98  | 3.63  | 2.31    | 73.00               |
| Cikuray | 1.34  | 3.60  | 2.47    | 62.78               |
| Average | 1.16b | 3.62a | 2.39    |                      |

Note: The numbers followed by the same letter in the same row or column are not significantly different according to Duncan's multiple range test at 5% level

The results illustrate the greatest decrease in dry weight of seeds found in Nanti variety. Decrease in the average dry seed yield for each variety reaches above 50%. Nanti is a variety with decreased root dry weight (Table 1), root volume (Table 2) and seed dry weight per plant (Table 5), which are greater than Cikurai variety. These greater decreases are due to the imperfect root growth and limited root distribution caused by low soil water content. Root growth and its ability to extract soil cause plants to lower in absorption and translocation of nutrients and water.

Plants absorb nutrients and water through the roots, and the uptake is determined by the amount of nutrients available in the soil and the demand from the root surface [14]. Absorption of minerals by plants is a process that depends on the root surface area and the ability of roots to absorb nutrients. The whole process of nutrient absorption and translocation rely on groundwater [15]. In plants experiencing drought stress, beside growth and development of roots are hampered, the rate of movement of nutrients in the soil and from the soil to the roots is also obstructed. The process of mass flow and nutrient diffusion is hampered caused by this drought stress [16]. In addition, the process of soil mineralization, microbial activity and enzymes activity is entirely dependent on the presence or absence of groundwater. All of these obstacles will result in the unavailability of energy used for pod filling. Obstacles in the absorption, translocation and metabolism of these plants are thought to cause low yield of dried soybeans under drought stress condition.
4. Conclusion
Nanti variety at 20% FC groundwater content experienced a percentage decrease in root dry weight, root volume, root length, shoot dry weight, and dry seed yield with the values of: 58.33; 73.2; 24.85; 69.63 and 73.00%, respectively. Cikuray variety experienced a decrease in root dry weight (55.17%), root volume (43.8%), root length (47.13%), shoot dry weight (71.05%), and dry seed yield (62.78%), respectively.

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