

Physiological response and growth of soybean [*Glycine max* (L.) Merr.] 'Dega 1' in different water availability

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ABSTRACT. One of the causes of the decrease in soybean production is the characteristics of soybeans that are sensitive to waterlogging and drought. 'Dega 1' is a superior soybean cultivar that has the advantages of high yield potential, early maturity, and large seed size. Early maturity can reduce the risk of plants to stress, both biotic and abiotic. This study aimed to analyze the physiological response and growth of soybean 'Dega 1' in different water availability. This study used a completely randomized design (CRD) with two factors: water availability and treatment duration. Three different levels of water availability (100% field capacity, 50% field capacity, and inundated up to 2 cm) and three different levels of treatment duration (7 days, 14 days and 21 days). Plant height, leaf area, root length, number of adventitious roots, plant fresh and dry weight, physiological characters (membrane stability index, relative water content, nitrate reductase activity, leaf chlorophyll, and carotenoid content) were among the variables studied. Observed data were analyzed by analysis of variance and a significant difference between treatments is continued with Duncan's multiple distance test at a 95% confidence level. The results showed that the availability of water up to 2 cm inundated resulted in the lowest growth and physiological yield. Soybean plants with water availability up to 2 cm inundated for 21 days had the lowest carotenoid content and nitrate reductase activity, at 0.27 mg/g FW and 0.15 $\mu\text{mol/g/hour}$. The longer the inundation, the slower the soybean growth. Drought tolerance of the soybean 'Dega 1' is up to 50% of field capacity for 21 days. In comparison to water availability at 100% field capacity, soybean 'Dega 1' was able to raise 2.38% carotenoid content and 5.26% nitrate reductase activity when given water at 50% field capacity for 21 days.

Keywords: drought stress; field capacity; nitrate reductase activity; soil moisture; waterlogging stress

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INTRODUCTION

National soybean needs averaged 2.8 million tons per year from 2013 to 2020, with 3.25 million tons expected in 2021 (Aldillah, 2015; Sekjen Pertanian, 2021). Soybean production only reached 480,000 tons in October 2019 and 613,318 tons in 2021 (Antonius & Pericarditis, 2021; Sekjen Pertanian, 2021), so soybean imports were carried out with a total of 2,67 million tons (Faustian, 2021). According to this data, the high demand for national soybeans is not being met by high soybean production. Environmental conditions have an impact on the soybean production. Because soybeans are very sensitive to flooding (Oh *et al.*, 2014) and drought, the availability of water in the planted area has an effect on soybean growth and production (Malefic *et al.*, 2013). Based on these concerns, the Research Center for Various Nuts and Tubers (Balitkabi) has been focusing on generating new superior seeds with high output, large seed size, and early maturity that are adaptable to suboptimal land. 'Dega 1' is a superior seed that was introduced in 2016 with high yield potential, high average yield, early maturity, and large seed size (Nugrahaeni, 2016).

Drought is one of the most common abiotic stresses affecting plant growth and yield (Du *et al.*, 2020). Drought stress can directly cause various symptoms in soybeans, including increased oxidative stress, a significant decrease in the photosynthetic capacity of soybean leaves, stomatal conductance, transpiration rate and metabolism of shoot and root tissue (Kunert *et al.*, 2016; Du *et al.*, 2020). Increases in plant height and leaf area were slowed by drought stress. This inhibition became more significant as the level, duration, and frequency of drought stress increased (Dong *et al.*, 2019). The small amount of water availability causes changes in root architecture (root depth, root branching density, and root angle), decreased root lengths, and dry biomass accumulation in many soybean

accessions under drought conditions (Widiatmoko *et al.*, 2012; Fenta *et al.*, 2014; Thu *et al.*, 2014; Rosawanti, 2016). Drought-tolerant soybean genotypes respond to water stress by maintaining a higher leaf expansion rate, net photosynthetic rate, chlorophyll content, relative water content (RWC), and root growth during progressive soil drying (Hossain *et al.*, 2014).

All plants need water to survive, but excessive watering, waterlogging, or flooding, causes stress and prevents gas exchange between soil and the atmosphere (Wang *et al.*, 2017). Excess water causes waterlogging stress which creates a hypoxic situation, once the condition of hypoxia has occurred, a deviation from aerobic to anaerobic pathway takes place, inducing changes in the respiratory metabolism of the root system. Abrupt changes in respiratory metabolism, in turn, produce toxic metabolites like ethanol (C₂H₅OH), which increase the activity of fermentative enzymes (Beutler *et al.*, 2014; Borella *et al.*, 2014). Hypoxia further leads to decreased biological nitrogen fixation as sufficient O₂ is needed by nodules to carry aerobic respiration and supply adenosine triphosphate, which is essential for maintaining nitrogenase activity (Tewar & Arora, 2016). Soybean crops are commonly intolerant of waterlogged stress (Tougou *et al.*, 2012). Waterlogging stress affects soybean growth, development, and yield in various ways. It reduces chlorophyll content, root and shoot growth, pH, biomass production, and may also intensify the infection and growth of harmful plant diseases (Sakazono *et al.*, 2014; Dhungana *et al.*, 2019). Soybeans respond to waterlogging by allocating photosynthesis through adventitious roots and aerenchyma formation (Tri, 2016). Plants can still take in oxygen from the air to carry out aerobic respiration in waterlogged conditions because of adventitious roots, which act as a conduit for O₂ (Stefia & Saputro, 2017). Along with the increase in inundation concentrations, the number of adventitious roots also increased significantly (Mahendra *et al.*, 2019).

This study aimed to analyze the physiological response and growth of soybean 'Dega 1' under different water availability. Provide information on effective water availability conditions for the growth of soybean 'Dega 1' and to determine the level of soybean 'Dega 1' tolerance under waterlogging and drought stress. The results can be used to develop soybean varieties like 'Dega 1' that are resistant to waterlogging and drought stress.

MATERIALS AND METHODS

Plants and Cultivation Media Source. 'Dega 1' soybean seeds were obtained from the Research Institute for Legumes and Tubers (BALITKABI), Malang, Indonesia. Soybean seeds were soaked in aquadest for 6 hours before being planted in a portray containing growing media for 7 days. The seeds that sprouted the first two leaves were placed at polybags (size 17,5 cm width x 35 cm length) containing 2 kg of garden soil, 0.5 kg of husk charcoal, and 0.5 kg of organic compost, for a total weight of 3 kg/polybag (Fatimah & Saputro, 2016) and acclimatized for 14 days. Water content is determined by watering planting media in polybags until they drip, then allowing them to sit for 3 days until no water drips. The wet weight (W_w) of the soil was determined using a sample of 10 g of soil taken from a polybag. The sample was dried in an oven at 105°C for 24 h until a consistent weight was achieved. The obtained results were weighted to determine the soil's dry weight (W_d) (Haridjaja *et al.*, 2013). The formula for calculating water needs based on field capacity is (Haridjaja *et al.*, 2013):

$$FC\% = \frac{W_w - W_d}{W_d} \times 100\%$$

Treatment. After the acclimatization period, soybean plants were watered with varying amounts of water. Water availability is classified into three levels: 100% field capacity (K0), 50% field capacity (K1), and up to 2 cm inundated (K2). The duration of each treatment was different, ranging from 7 days (H1) to 14 days (H2) to 21 days (H3). Watering was carried out once every 3 days. Meanwhile, the volume of water was checked every day for inundated plants. After each treatment interval, data on soybean plants was collected at 28 Days After Planting (DAP), 35 DAP, and 42 DAP, respectively. After the treatment interval ended, soybeans were grown in field capacity

conditions, and growth was continued until the soybean plants produced fruit and seeds (harvest) at the age of 73 DAP.

Plant photosynthesis pigments. The content of chlorophyll and carotenoids in leaves was determined using a spectrophotometer based on the colorimetric method (Holden, 1965). The leaves of 0.1 g in weight were mashed in a mortar until smooth, then filtered, and placed in a test tube with 10 mL of 80 percent acetone. The absorbance of the supernatant was calculated at a wavelength (λ) of 663, 645, and 470 nm using a spectrophotometer (Spectronic 21). Chlorophyll and carotenoid content were estimated by the following equation (Holden, 1965):

$$\text{Ch a (mg L}^{-1}\text{)} = (12.7 \times A_{663}) - (2.69 \times A_{645})$$

$$\text{Ch b (mg L}^{-1}\text{)} = (22.9 \times A_{645}) - (4.68 \times A_{663})$$

$$\text{Ch total (mg L}^{-1}\text{)} = (20.2 \times A_{645}) - (8.02 \times A_{663})$$

$$\text{Carotenoid (mg L}^{-1}\text{)} = ((1000 A_{470}) - 3.27 (\text{Ch a}) - 104(\text{Ch b}))/227$$

$$\text{Conversion (mg g}^{-1}\text{)} = (1/100 \times \text{total chlorophyll content})/\text{FW sample}$$

Nitrate reductase activity (NRA). Measurement of NRA was assayed in vivo according to the method from Thomas & Hilker (2000) with a modification. The third leaf from the top of the plant was picked around 9-10 am as an observation sample and 0.5 g fresh leaves were chopped into small pieces. The leaf pieces were then placed in a dark tube with 5 mL of phosphate buffer solution (pH 7.5) and soaked for 20 minutes. The buffer solution was removed after 20 minutes and replaced with a new 5 mL buffer solution. After that, 0.1 ml of 5 M NaNO₃ was added to each dark tube and incubated for 60 minutes. Following the incubation period, 0.1 ml of the filtrate was placed in a test tube with 0.2 mL of a 0.02% naphthylethylendiamide solution and 0.2 mL of a 1% sulfanilamide reagent diluted in 3 N HCl. The filtrate was incubated for 15 minutes until the dye reagent reduced NO₂, resulting in pink color. Furthermore, 2.5 mL of distilled water was added as a color diluent. The absorbance of the solution was measured using a spectrophotometer cuvette at a wavelength of 540 nm.

Membrane stability index (MSI). MSI measured by the electrolyte leakage technique that is used as tolerance index for abiotic stresses according to the method described by Swapna and Shylaraj (2017) was carried out when the plants were at 28 DAP, 35 DAP, and 42 DAP. Leaf samples of 100 mg (without midrib) were taken and cut to a size of ± 5 mm². The leaves were placed in a test tube with 100 mL of ddH₂O and incubated for 20 hours in a room with controlled temperature and lighting. The initial conductivity value was determined using an EC meter (EC₁). The tube was heated in boiling water for 30 minutes (100°C) and then cooled for 15 minutes at 25°C. The final conductivity value (EC₂) was measured using an EC meter. The percentage of electrolyte leakage was calculated using the following formula (Swapna & Shylaraj, 2017):

$$\text{EL} = \frac{\text{EC}_1}{\text{EC}_2} \times 100$$

The membrane stability index value is then calculated by the following formula:

$$\text{MSI} = \left(1 - \frac{\text{EC}_1}{\text{EC}_2}\right) \times 100$$

Relative water content (RWC). RWC was measured using the method by Smart and Bingham (1974). The middle leaf samples were taken $\pm 5 \times 2$ cm² and the fresh weight (FW) was measured when the plants were at 28 DAP, 35 DAP, and 42 DAP. To obtain maximum turgidity (TW), samples were immersed in ddH₂O for 24 hours under constant lighting. The samples were heated at 65°C for 72 hours. After that, the sample was weighed for dry weight (DW) measurement. Relative water content was calculated by the following equation (Smart & Bingham, 1974):

$$\text{RWC} = \frac{\text{FW} - \text{DW}}{\text{TW} - \text{DW}} \times 100$$

Growth analysis. Plant height was measured every week for each plant in each treatment. Leaf area, root length, number of adventitious roots, fresh weight and dry weight of plants were measured at 28 DAP, 35 DAP, 42 DAP. The gravimetric method was used to calculate the leaf area, and then the regression method was used to continue (Irwan & Wicaksono, 2017). The dry weight of the plants

was determined by separating the shoots and roots, drying them in an oven for around 2 days at 70°C, then weighing them until they reached a constant weight (Gardner *et al.*, 1991).

Data analysis. Quantitative data were analyzed using analysis of variance (ANOVA) in SPSS software (version 23), and if a significant difference was found, DMRT was used to find the significant difference between treatments at the 95% significance level.

RESULTS AND DISCUSSION

Plant photosynthetic pigments. Differences in water availability and duration of treatment affect the level of chlorophyll a, chlorophyll b, and carotenoids. The availability of water at 50% field capacity for 7 days caused a decrease in chlorophyll a by 14.15%, chlorophyll b by 23.81%, and carotenoids by 11.11%. The decrease in chlorophyll production occurred because the lack of water inhibited the synthesis of chlorophyll in the leaves, resulting in lower photosynthesis as well as an increase in temperature and transpiration. Ultimately, all of these factors promote the disintegration of chlorophyll (Sharifi *et al.*, 2012). After 14 and 21 days of treatment with water availability of 50% field capacity, soybeans 'Dega 1' had higher levels of chlorophyll and carotenoids. In this study, increased levels of chlorophyll and carotenoids in plants exposed to drought stress indicated no chlorophyll degradation. The rates of chlorophyll and carotenoids increased in proportion to the leaf surface area, which was also the widest in 'Dega 1' soybeans with water availability at 50% field capacity (Table 1). Proklamasiningsih *et al.* (2012) explain that the wider leaf surface is expected to contain more chlorophyll because nitrogen functions in protein metabolism in the formation of chlorophyll.

Table 1. Physiological characters of 'Dega 1' at 28 DAP, 35 DAP, and 42 DAP under different conditions of water availability and duration of treatment.

Treatment	Treatment duration 7 days (H1) at 28 DAP					
	Ch a (mg/g FW)	Ch b (mg/g FW)	Carotenoid (mg/g FW)	NRA ($\mu\text{mol/g/hour}$)	MSI (%)	RWC (%)
Treatment duration 7 days (H1) at 28 DAP						
K0	1.06 ^b	0.84 ^c	0.45 ^b	1.85 ^b	80.64 ^a	62.54 ^a
K1	0.91 ^b (-14.15%)	0.64 ^b (-23.81%)	0.40 ^b (-11.11%)	1.43 ^b (-22.70%)	82.88 ^a (2.78%)	73.94 ^a (17.75%)
K2	0.65 ^a (-38.68%)	0.41 ^a (-51.19%)	0.29 ^a (-35.55%)	0.67 ^a (-63.78%)	85.75 ^a (6.34%)	66.86 ^a (6.91%)
DMRT	*	*	*	*	ns	ns
Treatment duration 14 days (H2) at 35 DAP						
K0	1.19 ^b	1.08 ^b	0.48 ^b	0.68 ^b	81.34 ^a	82.08 ^b
K1	1.25 ^b (5.04%)	1.25 ^b (15.74%)	0.51 ^b (6.25%)	0.89 ^b (30.88%)	81.87 ^a (0.65%)	76.96 ^b (-6.24%)
K2	0.88 ^a (-26.05%)	0.63 ^a (-41.67%)	0.37 ^a (-22.92%)	0.32 ^a (-52.94%)	80.40 ^a (-1.15%)	62.75 ^a (-23.55%)
DMRT	*	*	*	*	ns	*
Treatment duration 21 days (H3) at 42 DAP						
K0	0.98 ^b	0.89 ^b	0.42 ^b	0.38 ^b	88.11 ^a	87.22 ^a
K1	1.03 ^b (5.10%)	0.95 ^b (6.74%)	0.43 ^b (2.38%)	0.40 ^b (5.26%)	71.61 ^a (-18.73%)	93.85 ^a (7.60%)
K2	0.66 ^a (-32.65%)	0.51 ^a (-42.70%)	0.27 ^a (-35.71%)	0.15 ^a (-60.53%)	72.81 ^a (-17.36%)	86.10 ^a (-1.28%)
DMRT	*	*	*	*	ns	ns

Notes: numbers followed by the same letter in one column indicate no significant difference based on the 95% confidence level DMRT test. The number in brackets represents the percent (%) change to the control. (*) The difference is significant; (ns) the difference's value is not significant.

All the soybean plants with water availability of up to 2 cm inundated showed a significant decrease in chlorophyll content due to waterlogging treatment after 7, 14, and 21 days of treatment (Table 1). These results show that 'Dega 1' soybeans are more susceptible to waterlogging, as study results by Kim *et al.* (2019) show that the chlorophyll content of susceptible resources decreases after

3 days of inundation. The longer the treatment days, the greater the reduction of chlorophyll content by water-logging treatment. Waterlogging causes the pH of the media to decrease (acidic), reducing N and Mg absorption and disrupting the activity of Rhizobium soil microorganisms. Garcia *et al.* (2020) discovered that the H₂O₂ content increased in water-logged soybean plant leaves. The rise in H₂O₂ in plant leaves is generated by a disruption in the photosynthetic process induced by decreased stomata opening and pigment degradation. Under these conditions, the accumulation of light causes an overabundance of the electron transport chain in the chloroplast, resulting in electron leakage and ROS accumulation.

Nitrate reductase activity (NRA). Differences in water availability and treatment duration affected nitrate reductase activity in 'Dega 1' soybeans. Soybeans with water availability at 50% field capacity for 14 and 21 days had NRA values that were 23% and 5% higher than plants with 100% field capacity. The increase in NRA under drought conditions indicates that 'Dega 1' soybean is a drought-tolerant crop with water availability of up to 50% of field capacity for 14 and 21 days. This is due to the soybean 'Dega 1', which can maintain its chlorophyll content (Table 1) even when water is only available at 50% of field capacity. The absence of a decrease in chlorophyll content in plants maintains the rate of photosynthesis, where the photosynthesis process produces NADPH₂ during the light reaction, and NADPH₂ is produced to support the activity of the nitrate reductase enzyme when reducing nitrate to nitrite (Irmayanti *et al.*, 2015).

Plants that were inundated with up to 2 cm of water had a lower NRA at all treatment periods. The decrease in NRA was quite large, up to 60.53% at 21 days of treatment. The reduction in NRA of waterlogged soybean leaves could be due to a reduction in nitrate imports from roots as a result of waterlogging. Nitrates induce nitrate reductase activation, so the decrease in nitrate reductase activity observed in waterlogged soybean leaves may be attributed to low nitrate translocation from roots (Da-Silva *et al.*, 2021). When soybeans reached the flowering stage, they were waterlogged for 21 days. According to Bellaloui *et al.* (2014), soybean plants require the most N during the flowering phase to form vegetative and generative organs, resulting in a significant decrease in NRA in soybean plants after a 21-day inundation period.

Membrane stability index (MSI). Table 1 reveals that changes in water availability or treatment duration do not affect the membrane stability index (MSI) of soybean 'Dega 1'. MSI spread decreased by 18.73% in plants with 50% water availability in the field capacity and by 17.36% in plants with up to 2 cm inundation. The availability of water at 50% field capacity causes drought stress in 'Dega 1' soybeans, which results in a decrease in MSI. Drought stress causes stomata to close to prevent excessive water loss in plant leaves. This process will cause a decrease in CO₂ in the leaves, and as CO₂ decreases, only a small amount of NADPH is required for carbon reduction, resulting in a buildup of NADPH and over reduction in the plant's photosynthetic light system. Because of the excess of photosynthetic electrons in the leaves, oxygen in the leaves binds to photosynthetic electrons, resulting in radical oxygen compounds (ROS). The formation of ROS indicates that the plant is under oxidative stress (Abid *et al.*, 2018; Sakya *et al.*, 2018). Increased ROS can cause damage to cell membrane components. Lipids (peroxidation of unsaturated fatty acids in membranes), proteins (denaturation), carbohydrates, and nucleic acids are the main cellular components susceptible to free radical damage. Changes in lipid composition and content, activation of lipid peroxidase, and increased membrane leakage are all indicators of membrane damage (Broughton *et al.*, 2015).

Relative water content (RWC). The difference in water availability did not affect the relative water content (RWC) of soybeans after 7 and 21 days of treatment. However, it did affect RWC after 14 days of treatment (Table 1). The duration of treatment for 14 days caused a decrease in RCW in 'Dega 1' soybeans with water availability of up to 2 cm inundated and at 50% water availability of field capacity. This study's findings are similar to those of a study (Deshmukh & Gaikwad, 2019), which found that water deficit stress and waterlogging stress disrupt the water balance in spinach plants (*Basella alba* L.), resulting in lower RWC. Reduced RWC in waterlogging stressed plants is due to plants' inability to maintain water balance under conditions of increased reactive oxygen

species, decreased root hydraulic conductivity, stomatal conductance, and mineral nutrient availability caused by plants' tendency to switch from aerobic to anaerobic respiration due to waterlogging (Ashraf, 2012). The higher transpiration rate in plants than the rate of water absorption by roots can cause a decrease in RWC at 50% water availability of field capacity (Dewi *et al.*, 2019). The decrease in RWC reduces leaf stomatal conductance, lowering the CO₂ concentration in the leaf and slowing photosynthesis (Lakitan, 2013).

Plant growth characters. The availability of water up to 2 cm inundated causes delays in the growth of the soybean 'Dega 1'. When compared to plant root length with 100% water availability at field capacity, waterlogged soybeans had the smallest increase in plant height, the smallest leaf area, and a 45% decrease in root length. Waterlogging inhibits soybean growth because it interferes with the process of cell division and nutrient absorption from the soil. Waterlogging causes the soil pores to be filled with water and saturated with water. That makes the amount of available oxygen (O₂) limited. The limited O₂ will change the respiratory pathway to an anaerobic /fermentation pathway where anaerobic respiration is less efficient in converting ADP to ATP. This condition makes the availability of metabolic energy limited and inhibits cell division (Sauter, 2013). Under waterlogged conditions, plant photosynthesis is also slowed, resulting in a lower allocation of photosynthate to plant organs (Nurbaiti *et al.*, 2012). Plant save energy by reducing leaf area growth as one of their defenses to survive in these conditions.

Table 2. The Growth of soybean 'Dega 1' at 28 DAP, 35 DAP, and 42 DAP under different conditions of water availability and duration of treatment.

Treatment	Plant height (cm)	Leaf Area (cm ²)	Root Length (cm)	Adventive Roots	Roots FW (g)	Shoots FW (g)	Roots DW(g)	Shoots DW (g)
Treatment duration 7 days (H1) at 28 DAP								
K0	99.64 ^b	27.17 ^{ab}	43.90 ^b	0.00 ^a	5.20 ^a	14.20 ^b	0.52 ^b	2.51 ^b
K1	108.60 ^b	29.21 ^b	45.04 ^b	0.00 ^a	4.20 ^a	11.60 ^{ab}	0.47 ^b	2.44 ^b
K2	80.38 ^a	20.08 ^a	24.30 ^a	4.00 ^b	4.60 ^a	10.00 ^a	0.38 ^a	1.41 ^a
Treatment duration 14 days (H2) 35 DAP								
K0	129.18 ^b	45.80 ^b	47.40 ^b	0.00 ^a	14.40 ^c	22.80 ^b	1.33 ^b	4.84 ^b
K1	124.66 ^b	50.41 ^c	44.90 ^b	0.00 ^a	10.80 ^b	18.60 ^b	1.15 ^b	3.91 ^b
K2	105.80 ^a	34.80 ^a	28.00 ^a	7.80 ^b	7.00 ^a	11.20 ^a	0.49 ^a	2.61 ^a
Treatment duration 21 days (H3) 42 DAP								
K0	121.70 ^a	52.95 ^b	52.60 ^b	0.00 ^a	12.80 ^b	24.40 ^b	1.27 ^b	7.45 ^b
K1	120.70 ^a	54.35 ^b	53.60 ^b	0.00 ^a	10.60 ^{ab}	22.20 ^b	1.34 ^b	8.74 ^b
K2	119.56 ^a	29.57 ^a	28.80 ^a	11.60 ^b	9.20 ^a	14.80 ^a	0.95 ^a	4.98 ^a

Notes: Based on the 95% confidence level DMRT test, numbers followed by the same letter in one column indicate no significant difference.

In the treatment of differences in water availability over 7 days, the fresh weight of soybean plants was not significantly different (Table 2). This result shows that 'Dega 1' soybeans can adapt to water stress for 7 days in the presence of waterlogging and drought. These abilities are influenced by the short duration of stress treatment and stress applied during the early stages of plant growth, according to Dong *et al.* (2019), who discovered that lighter, shorter, and less frequent water stress levels resulted in more significant compensation. The duration of treatment had a significant impact on the fresh weight and dry weight of soybean plants, with differences in water availability for 14 days and 21 days. Plants with 50% field capacity water availability had lower fresh weight and dry weight than soybean plants with 100% field capacity water availability. Due to a lack of water, the nutrient content in the soil is difficult to absorb by the roots, and the reduced supply of nutrients that dissolve with water causes the formation of plant organic matter to decrease, resulting in a decrease in the shoot's dry weight (Wahono *et al.*, 2018). Root dry weight decreased in plants with limited water availability because a lack of water prevents large-scale transport of carbohydrates through the phloem as an energy source for the development of the apical zone of roots, which can aid in root growth (Mangena, 2018).

Soybeans form adventitious roots in response to waterlogging stress conditions (Steffens & Rasmussen, 2016). When a plant is hypoxic, adventitious roots replace the original root system to help sustain oxygen supply (O₂ deficiency) (Sauter, 2013). Adventitious roots only appeared in inundated plant environments where the number of adventitious roots increased as the inundation lasted longer (Table 2). By expanding the root area into the air, increasing aerobic respiration, and oxidizing the rhizosphere, adventitious roots reduce the negative effects of (Sakazono *et al.*, 2014). Because the rate of gas diffusion in water is 10,000 times slower than in air, a flooded plant lacks oxygen availability and accumulates the hormone ethylene gas in submerged tissues. The accumulation of ethylene increases the sensitivity of the root-forming tissue, triggering the development of adventitious roots. Soybean adventitious root development takes time to form and function properly; roots only grow by 1 cm after 4 to 5 days of waterlogging (Voesenek & Bailey-Serres, 2013).

According to research, 'Dega 1' soybeans are drought tolerant up to 50% of the field capacity of water availability. The data from this study can be used as a reference for the development of 'Dega 1' soybeans into superior soybean seeds with early maturity that are drought tolerant, so that 'Dega 1' soybeans can be the soybean seeds of choice to support the achievement of national soybean production goals.

CONCLUSION

Soybean 'Dega 1', which was inundated up to 2 cm for 7, 14, and 21 days, had the lowest chlorophyll content and inhibited plant growth when compared to soybeans with 100% and 50% water availability at field capacity. The availability of water at 50% field capacity increased the leaf area, root length, and chlorophyll content of 'Dega 1' soybeans. Soybean 'Dega 1' is more tolerant of drought stress than waterlogging. Drought tolerance of the soybean 'Dega 1' is up to 50% water availability at field capacity for 21 days.

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