Plant growth of genotypes of Arabica coffee on water stress

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Abstract. Drought tolerant genotype has to be created due to changing of world climate. Performance of Arabica coffee offspring might be affected by parental environment. In North Sumatra province of Indonesia, Arabica coffee were growing at a wide range of elevation, precipitation and temperature. Hence, drought tolerant genotype might be available in this coffee plantation. The objectives of this research were to determine effect of water stress on performance Arabica coffee genotypes. Seven genotypes which were selected from seven different environments as well as four level of water treatments (100%, 75%, 50%, and 25% field capacity) were used. Parameters were increment of plant height, stem diameter, and leaf number. Factorial experiment namely completely block design with two factors and three replications was conducted in the green house. The result revealed that interaction of genotype and level of water treatment was highly significant. Genotype Tobe2 seemed to be the most tolerant to water stress. Increment of leaf number of descendant had a negative significant correlation with minimum precipitation of parental environment. Increment of stem diameter of offspring positively significantly correlated with average temperature of parental environment. It could be concluded that it could be possible to carry out selection for drought tolerant genotype from the existing population of Arabica coffee. However, selection should be conducted in a controlled condition due to significant GxE interaction.

1. Introduction
In North Sumatra province of Indonesia, Arabica coffee was very important because the family income of 151000 coffee farmers (household) depended on the sale of green beans. This province produced 49000 ton of green beans and had 59600 ha of Arabica coffee plantations [1] and delicious coffee [2]. In this province, coffee farms located at a wide range of climate zone, elevation and temperature. However, the future of this Arabica coffee has become threatened by changing of climate due to decrement of precipitation in wet seasons and increment of precipitation in dry seasons in this province [3]. Among meteorological parameters, water deficit was the most important [4].

Plant breeders around the world have been trying to create drought tolerant genotype because of the climate changing in the globe. However, the effort has not been successful yet. The results of various studies provided hope that drought tolerant genotype would be created.
because of some success indicators. Selection for drought tolerance could be potential in coffee genotypes ([5], [6], [7]).

Plant drought tolerance was controlled by genes whereby drought tolerant genotypes obstructed efficiency of water use, reduced leaf area, decreased stomatal opening, increased proportion of biomass allocation to the stems, folded leaf, and deeped root system ([5], [8], [9], [10], [11], [12], [13]).

Generally, consequences of water deficit were reduction of photosynthesis in leaf, die-back, and yield decrement ([9], [14], [15]). In contrary to water deficit, continuous waterlogging could cause premature dropping of leaves and decrement of root area [16].

Parental environment of Arabica coffee in Ethiopia could affect performance of coffee offspring as well as interaction of offspring genotype and its growth environment might be significant [6]. Because Arabica coffee in North Sumatra Province were growing at a wide range of environmental condition, performance of descendant might be different due to this parental environment. However, information on effect of parental environment on descendant performance of genotype Arabica coffee found in this province was not yet available.

The objectives of this research were to determine respons of genotype to water stress as well as to investigate correlation of parental environment with performance of descendant of Arabica coffee genotype growing in the province of North Sumatra of Indonesia. The hyphotesis of this research were (1) genotypes (G) were significantly different in response to water treatment (W), (2) effect of water treatment varied significantly, and (3) interaction of genotype and water treatment were significant. Besides, it was hypothesized that parental environment had significant correlation with offspring performance.

2. Materials and Methods
Seven Arabica coffee genotypes Huma1, Simb1, Pakc1, Samd1, Daid2, Tape1 and Tobe2 from climate zones A1, B1, C1, D1, D2, E1 and E2 [3]. Seedlings with five months old and similar height and leaf number were used. Randomized completely block design with two factors and three replications was used [17]. The experiment was conducted in the green house of Agriculture Faculty of Nommensen HKBP University in Medan. According to [19], field capacity as water treatment was determined. Soil of three seedlings was weighed (S₀ gram). After soil saturation, soil was allowed to drain 48 hours with gravity force. Then, this soil was weighed (Sₚ₀ gram). The difference weight between Sₚ₀ and S₀ was the amount of water (Wₛ₀) which was needed to make the field capacity (Wₛ₀ = Sₚ₀ - S₀ ml). The amount of water for the treatment 100%, 75%, 50% and 25% field capacity was 1 x Wₛ₀, 0.75 x Wₛ₀, 0.50 x Wₛ₀, and 0.25 x Wₛ₀ ml, respectively. Since symptom of plant water deficit was indicated by folded leaf [11], the addition of water was carried out when there was already a folded leaf on one polybag. This trial lasted for 3 months. During the experiment, the addition of water according to the treatment were eight times. Before treatment, data of plant height (PH₀), stem diameter (SD₀), and number of leaf (NL₀), were recorded. At the end of experiment, data of plant height (PH₁), stem diameter (SD₁), and number of leaf (NL₁), were recorded. Increment was defined as the difference between these parameters at the end and the beginning of the experiment. The source of length of rainy season and precipitation data of the climate zones was [3]. Data of the temperature of the selected farms were taken from districts statistics and [17]. Garmin GPS MAP 78s was used to measure the altitude of the selected farms of coffee. Following [18], analysis of variance, comparison between treatment, and simple correlation was conducted by using Microsoft Office Excell Version 2007.
3. Result
Interaction of genotype and water treatment in plant height increment, stem diameter increment, and leaf number increment was highly significant (α = 0.01 (Table 1).

Table 1. Mean square of plant height increment, stem diameter increment, and leaf number increment

| Parameter                  | Block (df = 2) | Treatment (T) (df = 27) | Genotype (G) (df = 6) | Water (W) (df = 3) | GxW interaction (df = 18) | Error (df = 54) | CV (%) |
|----------------------------|----------------|-------------------------|-----------------------|--------------------|----------------------------|-----------------|--------|
| Plant height increment (cm)| 0.08549 ns *** | 8.55992 ***             | 14.09413 ***          | 40.85171 ***       | 1.33322 ***                | 0.13391         | 17.79  |
| Stem diameter increment (cm)| 0.00003 ns *** | 0.00328 ***             | 0.00437 **            | 0.01399 **         | 0.00113 **                 | 0.00029         | 52.49  |
| Leaf number increment (cm) | 0.67857 ns **  | 14.80203 **             | 12.59524 **           | 36.71032 **        | 11.88624 **                | 1.24647         | 69.40  |
| F0.05                      | 3.17           | 1.67                    | 2.27                  | 2.78               | 1.76                       |                 |        |
| F0.01                      | 5.01           | 2.06                    | 3.15                  | 4.16               | 2.23                       |                 |        |

LSD = least significant difference at α = 0.05, the means in the same column which followed common letter were not significantly different at α = 0.05 level based on Fisher’s LSD test.

Genotype Huma1 performed the highest plant height increment (18.02 cm) in 75% field capacity while Daid2 had the highest increment of plant height (16.12 cm) in 100% field capacity (Table 2). Other genotypes performed the same increment of plant height both in 100% and 75% field capacity.

Table 2. Plant height increment (cm)

| Climate zone of selected farm coffee | District of selected coffee farm | Selected genotype | Plant height increment (cm) | 100% field capacity | 75% field capacity | 50% field capacity | 25% field capacity |
|-------------------------------------|----------------------------------|-------------------|-----------------------------|---------------------|---------------------|---------------------|---------------------|
| A1                                  | Humbang Hasundutan               | Huma1             | 16.52 de                    | 18.02 ab            | 16.21 d-g           | 12.99 w-y           |
| B1                                  | Simalungun                       | Simb1             | 16.11 d-i                   | 16.01 e-j           | 15.52 h-l           | 13.12 wx            |
| C1                                  | Pakpak Bharat                    | Pakc1             | 15.24 k-m                   | 15.14 k-n           | 14.53 o-r           | 12.54 x-α           |
| D1                                  | Samosir                          | Samd1             | 16.71 cd                    | 16.43 d-f           | 15.73 g-k           | 14.21 r-u           |
| D2                                  | Dairi                            | Daid2             | 16.12 d-h                   | 15.04 l-o           | 15.01 l-q           | 13.22 v-w           |
| E1                                  | North Tapanuli                   | Tape1             | 14.24 r-t                   | 14.02 r-v           | 12.73 w-z           | 12.03 q-β           |
| E2                                  | Toba Samosir                     | Tobe2             | 18.53 a                     | 18.01 a-c           | 15.02 l-p           | 14.32 rs            |

LSD0.05 = least significant difference at α = 0.05, the means in the same column which followed common letter were not significantly different at α = 0.05 level based on Fisher’s LSD test.
Trends of plant height increment of genotypes were different due to water treatment (Figure 1). Plant height increment of Huma1 significantly increased as field capacity decreased from 100% to 75%. However, the rest of genotypes performed decreased increment of plant height as field capacity decreased to 25%.

![Graph of plant height increment across different field capacities for various genotypes.](image)

**Figure 1.** Plant height increment of the genotypes on field capacity

Genotype Pakc1 showed the highest stem diameter increment (0.293cm) in 100% field capacity while Tobe2 had the highest stem diameter increment (0.290cm) in 75% field capacity (Table 3). Other genotypes showed the highest stem diameter increment in both these both 100% and 75% field capacity.
Table 3. Stem diameter increment (cm)

| Climate zone of selected coffee farm | District of selected coffee farm | Selected genotype | Stem diameter increment (cm) |
|--------------------------------------|----------------------------------|------------------|-----------------------------|
|                                      |                                  |                  | 100% field capacity | 75% field capacity | 50% field capacity | 25% field capacity |
| A1 Humbang Hasundutan                | Huma1                            | 0.253 c-i        | 0.280 a-c             | 0.233 f-o          | 0.213 n-v          |
| B1 Simalungun                        | Simb1                            | 0.223 l-s        | 0.230 i-q             | 0.227 i-r          | 0.180 x-α          |
| C1 Pakpak Bharat                     | Pakc1                            | 0.293 a          | 0.260 c-g             | 0.207 o-x          | 0.233 f-p          |
| D1 Samosir                           | Samd1                            | 0.250 d-l        | 0.260 c-h             | 0.203 q-y          | 0.150 β            |
| D2 Dairi                             | Daid2                            | 0.243 e-m        | 0.223 l-t             | 0.217 m-u          | 0.193 u-z          |
| E1 North Tapanuli                    | Tape1                            | 0.273 a-d        | 0.267 a-e             | 0.253 c-j          | 0.213 n-w          |
| E2 Toba Samosir                      | Tobe2                            | 0.260 c-f        | 0.290 ab              | 0.237 f-n          | 0.253 c-k          |

LSD<sub>0.05</sub> = least significant difference at α = 0.05, the means in the same column which followed common letter were not significantly different at α = 0.05 level based on Fisher’s LSD test.

Stem diameter increment showed different course due to field capacity (Figure 2). Huma1 and Tobe2 performed a significantly upsurge in stem diameter as field capacity decreased from 100% to 75%. The rest of genotypes had a decreased increment of plant height as field capacity decreased from 100% to 25%.

Figure 2. Course of stem diameter increment based on field capacity

Huma1 and Simb1 had the highest leaf number increment in 100% field capacity (Table 4). These genotypes showed the lowest increment of leaf number in 25% field capacity.
Table 4. Leaf number increment

| Climate zone of selected coffee farm | District of selected coffee farm | Selected genotype | Leaf number increment |
|--------------------------------------|----------------------------------|-------------------|----------------------|
|                                      |                                  |                   | 100% field capacity  | 75% field capacity  | 50% field capacity  | 25% field capacity  |
| A1                                   | Humbang Hasundutan               | Huma1             | 15.33 a              | 12.00 d-m           | 10.33 m-y           | 5.00 αβ             |
| B1                                   | Simalungun                       | Simb1             | 14.67 ab             | 11.00 i-x           | 9.33 x-z            | 5.67 α              |
| C1                                   | Pakpak Bharat                    | Pakc1             | 13.00 b-e            | 11.33 e-v           | 13.00 b-g           | 12.00 d-q           |
| D1                                   | Samosir                          | Samd1             | 11.67 e-s            | 11.67 e-t           | 11.33 e-y           | 12.67 d-i           |
| D2                                   | Dairi                            | Daid2             | 12.33 d-j            | 12.00 d-n           | 13.00 d-h           | 11.67 e-u           |
| E1                                   | North Tapanuli                   | Tape1             | 14.67 a-c            | 13.00 b-f           | 12.00 d-p           | 12.00 d-r           |
| E2                                   | Toba Samosir                     | Tobe2             | 12.33 d-k            | 12.00 d-o           | 13.67 a-d           | 12.33 d-l           |
| LSD0.05                              |                                  |                   | 1.82                 |

LSD0.05 = least significant difference at α = 0.05, the means in the same column which followed common letter were not significantly different at α = 0.05 level based on Fisher’s LSD test.

Due to field capacity, leaf number increment showed different direction (Figure 3). Tobe2 had the same increment of leaf number in all field capacity. The rest of genotypes showed a significantly decrement of leaf number increment as field capacity decreased from 100% to 25%.

![Figure 3. Direction of leaf number increment due to field capacity](image)

Plant height increment highly significantly correlated with leaf number increment (r = 0.697**) (Table 5). Stem diameter increment performed a significant correlation (r = 0.394*) with average temperature at coffee farms. Leaf number increment had a negative significant correlation with minimum precipitation at coffee farms (r = -0.381*).
Table 5. Simple correlation coefficient (r, above) and determination coefficient ($r^2$, below) among parameters of plant growth and parameters of precipitation, altitude and temperature of seeds producing site.

|       | SDI (cm) | LNI (cm) | AvP (mm) | MiP (mm) | MaP (mm) | Ele (m asl) | AvT ($^\circ$C) |
|-------|----------|----------|----------|----------|----------|-------------|----------------|
| PHI (cm) | 0.371   | 0.697 ** | 0.136 ns | -0.014 ns | 0.077 ns | -0.099 ns | 0.105 ns |
|       | 0.138 ns | 0.486    | 0.018    | 0.002    | 0.006    | 0.010      | 0.011      |
| SDI (cm) | 1       | 0.343 ns | -0.054 ns | -0.154 ns | -0.010 ns | -0.321 ns | 0.394 * |
|       | 0.118 ns | 0.003    | 0.024    | 0.001    | 0.103    |            | 0.155      |
| LNI (cm) | 1       | -0.343 ns | -0.381 * | -0.250 ns | 0.052 ns | 0.003 ns | 0.00001 ns |
|       | 0.118 ns | 0.145    | 0.063    | 0.003    |          |             |             |

n = 28, * = significant at $\alpha 0.05 = 0.374$, ** significant at $\alpha 0.01 = 0.478$; ns = not significant; PHI = plant height increment (cm), SDI = Stem diameter increment (cm), LNI = Leaf number increment, (cm), AvP = average precipitation at coffee farms (mm), MiP = minimum precipitation at coffee farms (mm), MaP = maximum precipitation at coffee farms (mm), Ele = elevation of coffee farms (m asl), AvT = average temperature at coffee farms.

4. Discussion
This research result showed that amount of water deficit could be different on the genotypes (Table 2, Table 3, Table 4). This result indicated that these genotypes could have different ability in facing water deficit. These genotypes might have different critical amount of water deficit. A water deficit of 0.5-0.7 mm d$^{-1}$ stimulated the plant height and the stem diameter while deficit >0.7 mm d$^{-1}$ decreased the increment of these parameters [4].

Genotype Tobe2 which performed the same increment of leaf number at all field capacity conditions (Table 3) indicated that drought tolerant genotype could be available in coffee plantation in North Sumatera Province. This result was in line with [8] who proved the potential of selection for drought tolerant genotype in the wild and commercial Arabica coffee in Kenya.

The phenotype increments significantly correlated with minimum precipitation and average temperature of seed producing farm (Table 5). This indicated that selection for drought tolerance could be conducted on the basis of minimum precipitation and average temperature. However, since genotype and field capacity performed a highly significant interaction, selection for drought tolerant genotype should then be conducted in a controlled environment at laboratory.

This research showed that average temperature of the parental environment contributed more on the performance the descendant ($r^2 = 0.155$, Table 5) rather than minimum precipitation ($r^2 = 0.145$, Table 5). This result might be supported by the result research conducted by [20] who proved that biochemical composition of seeds were more affected by temperature rather than water availability.
5. Conclusion

Effects of water stress on plant growth of Arabica coffee genotype depended on the interaction of genotype and environment. Performance of descendant correlated with environment of parental genotype. Average temperature and minimum precipitation of parental environment had more effect on plant growth of descendant rather than elevation, maximum precipitation, and average precipitation. Due to significant GxE interaction, selection for drought tolerant genotypes should be carried out at a controlled environment.

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