Global climate change and increasing agricultural activity are the main causes of biotic and abiotic stresses, which negatively affect the plant growth and crop yields [Raza et al., 2019]. Abiotic stresses such as salinity, cold, waterlogging and drought have adverse impacts on crop yield and about 50–70% of crop yield reduction is attributed to such abiotic stresses [Francini & Sebastiani, 2019]. Drought stress is one of the most severe abiotic stresses that directly affect the growth and development of crop thus affecting its productivity [Yavad et al., 2019]. For instance, a recently published report indicates that between 1983– to 2005, 75% of global cultivated land (454 million hectares) experience drought-induced yield losses, which account to about 166 billion United States dollars [Kim et al., 2019]. The impact of drought on major crops has been reported in several studies, including meta-analyses and summary studies. Severe drought-induced crop yield losses of 14.0% and 21.8% were reported for maize and soybean, respectively [Wang et al., 2020]. Under drought, the wheat and rice yields decreased by 27.5% and 25.4%, respectively [Zhang et al., 2018]. Water stress reduced the yield attributes and grain yield in sorghum [Jabereldar et al., 2017]. Farooq et al. [2009] documented the economic yield reduction and critical stages of growth affected by drought stress in barley, maize, rice chickpea, and pigeon pea common

### ABSTRACT

Global climate change and increasing agricultural activity are the main causes of biotic and abiotic stresses, which negatively affect the plant growth and crop yields. The plant root system is the first organ for sensing the soil moisture limitation; therefore root growth under elevated water deficit is an important indicator for plant’s drought tolerance. Although the previous studies focused on the morphological traits of Napier grasses under water stresses, the root growth changes due to drought levels remain largely unclear. In order to evaluate variation in root performance to respond to drought stress, four cultivars named “Cỏ voi thuần” (CVT), King grass, Packchong, and VA06 were grown for 10 days under drought conditions under polyethylene glycol 6000 (PEG6000): 0% PEG6000 as control, 5% PEG6000, 10% PEG6000, 15% PEG6000 and 20% PEG6000. As compared to control, the root growth of all cultivars was reduced under drought treatments; however, significant variation in the root development response to drought levels was found. Among Napier cultivars, “Cỏ voi thuần” expressed drought-tolerant genotypes. The information on the root length, diameter, surface area and volume of the cultivars reveals interesting guidelines for further studies to explore the mechanisms behind root adaptation of Napier grasses to drought.

### Keywords
- Drought levels
- Napier grasses
- Root response
- Root length

### INTRODUCTION

Global climate change and increasing agricultural activity are the main causes of biotic and abiotic stresses, which negatively affect the plant growth and crop yields [Raza et al., 2019]. Abiotic stresses such as salinity, cold, waterlogging and drought have adverse impacts on crop yield and about 50–70% of crop yield reduction is attributed to such abiotic stresses [Francini & Sebastiani, 2019]. Drought stress is one of the most severe abiotic stresses that directly affect the growth and development of crop thus affecting its productivity [Yavad et al., 2019]. For instance, a recently published report indicates that between 1983– to 2005, 75% of global cultivated land (454 million hectares) experience drought-induced yield losses, which account to about 166 billion United States dollars [Kim et al., 2019]. The impact of drought on major crops has been reported in several studies, including meta-analyses and summary studies. Severe drought-induced crop yield losses of 14.0% and 21.8% were reported for maize and soybean, respectively [Wang et al., 2020]. Under drought, the wheat and rice yields decreased by 27.5% and 25.4%, respectively [Zhang et al., 2018]. Water stress reduced the yield attributes and grain yield in sorghum [Jabereldar et al., 2017]. Farooq et al. [2009] documented the economic yield reduction and critical stages of growth affected by drought stress in barley, maize, rice chickpea, and pigeon pea common
beams, sunflower, canola, soybean and potato. Besides field crops, drought stress also affect grasses and fodder crop growth, yield and productivity. Severe drought reduces the nutritive quality of forage legumes [Kuchenmeister et al., 2013, Liu et al., 2018]. Drought decreases the shoot and root biomass, plant height, tiller number and leaf growth of rhizomatous grasses (Pascopyrum smithii and Elymus lanceolatus) [Zhang et al., 2017]. Guinea (Panicum maximum) and Napier (Pennisetum purpureum Schumach.) grasses exhibit decreased plant height and herbage mass under drought stress [Purbajanti et al., 2012].

Napier grass (Pennisetum purpureum Schumach.), also known as elephant grass, is a major C₄ perennial forage crop grown in many tropical and subtropical regions of the world [Negawo et al., 2017]. Despite being native to East and Central Africa, Napier grass is currently distributed in Central and South America, Asia, Australia, Middle East and Pacific islands [Singh et al., 2013]. The factors behind the wide adoption of Napier grass as a fodder crop include; high forage productivity, rapid regeneration and fast growing characteristics, drought tolerance and high water use efficiency [Purbajanti et al., 2012, Kabirizi et al., 2015]. Napier grass, like many other C₄ plants, has numerous drought-coping adaptation mechanisms [Lopes et al., 2011]. During limited water availability, Napier grass exhibits a larger root system in combination with a less restrictive stomata regulation to maximize carbon assimilation [Cardoso et al., 2015].

Plant root systems play a crucial role in detecting the changes in soil moisture; thus, they develop appropriate drought survival mechanisms [Zhang et al., 2017]. It has been indicated that altering the root structure of crops grown under water stress can increase their yield [Lynch et al., 2014]. In different crops, root traits such as small fine root diameters, specific root length, root length density, specific root area and root angle have been suggested as desirable traits for improving plant productivity under drought stress [Comas et al., 2013, Wasaya et al., 2018]. Many studies on crops such as wheat, cow pea and rice have focused on the variation in root responses of cultivars to drought [Nguyen et al., 2015, Santos et al., 2020, Figueroa-Bustos et al., 2020, Kim et al., 2020, Fang et al., 2021]. In Napier grass, a few studies have focused on germplasm screening for water use efficiency under drought stress [Mwendia et al., 2016, Habte et al., 2019]. However, little is known about the root development response to drought stress in Napier grass. Therefore, in this study, four Napier grass varieties were assessed for their genetic variation in root development responses under drought stress.

**MATERIALS AND METHODS**

**Materials**

Four Napier cultivars named “Cỏ voi thuần” (CVT), King grass, Packchong and VA06 were used in this study. For each Napier grass, uniform stem cuttings were used, having 2 nodes that were 25 cm in length, 35 g in weight and 1.5 cm in diameter.

**Experimental design**

In order to induce root and bud development, the cuttings of each cultivar were inserted in humid sandy soil for 3 days. Then they were transplanted and fixed into position in the poly-styrene board with soft silicone rubber. The board with cuttings was then placed and floated on a modified Kimura B nutrient solution (composed of 0.36 mM Ca(NO₃)₂·4H₂O, 0.36 mM (NH₄)₂SO₄, 0.18 mM KH₂PO₄, 0.18 mM KNO₃, 0.54 mM MgSO₄·7H₂O, 10 μM,Fe(III)-EDTA, 18.8 μM H₂BO₃, 13.4 μM MnCl₂·4H₂O, 0.32 mM CuSO₄·5H₂O, 0.3 μM ZnSO₄·4H₂O, and 0.03 μM (NH₄)₆MoO₇·4H₂O) in a plastic container (61 cm × 42 cm × 20 cm). The root system in the container was continuously aerated by two air pumps 1.0 L min⁻¹ at opposite ends of the container. Seven days after transplanting (DAT), the plants were treated for 10 days under drought levels. In this study, polyethylene glycol 6000 was used to simulate drought stress. Five drought stress levels were 0% PEG6000 (control), 5% PEG6000, 10% PEG6000, 15% PEG6000 and 20% PEG6000 in the Kimura B solution (Fig. 1). The solutions were changed every 3 days to avoid nutrient depletion. The experiments were conducted in a greenhouse and designed with the randomized complete block design with 6 replications (6 boxes) per PEG6000 level treatment. A plant for each genotype in a box was used as a replication for data analysis.
Data collection

The root growth traits including root length (RL), diameter (RD), surface area (RSA) and volume (RV) were determined after 10 days under drought treatments, according to the method of previous studies [Nguyen et al., 2017; Nguyen et al., 2020]. By using an image scanner (V700/V750 2.08A-Epson), the root systems for each individual plant were imaged. The images were then analyzed by WinRhizo system (Regent Instruments, Inc., Quebec City, Canada) (Fig. 2) to investigate RL, RD, RSA and RV. RL was calculated by skeleton-based root analysis. Roots were classified into ten groups from $k_1, k_3, ..., k_{10}$ (mm) with unequal width ($1.5 > k_1 \leq 2.0$; $1.0 > k_2 \leq 1.5$; $0.5 > k_3 \leq 1.0$; $k_{10} \leq 0.5$) for RD measurements according to WinRhizo instruction. RSA and RV were determined by the following formulas: RSA = $\pi \times RL \times RD$ and RV = $\pi \times RL \times (\frac{RD}{2})^2$. The shoot dry weight (SDW) and root dry weight (RDW) values were evaluated after drying samples at 80 °C for 72 hours until constant weight.

Statistical analysis

The data were analyzed using R software. The effects of cultivar, drought, cultivar by drought interaction on the measured traits were analyzed by two-way ANOVA; separating mean values by Tukey’s honest significant difference test at P<0.05.
RESULTS

ANOVA analysis

Table 1 shows the data on the effects of cultivar (C), drought treatments (T), and their interaction (T×C) on the measured traits. It was found that C, T, and T×C had significant effects on all measured traits except RD.

Table 1. Data of two-way ANOVA analysis on the root and shoot growth traits of the Napier grasses under drought conditions

| Traits                  | Treatments (T) | Cultivar (C) | T x C   |
|-------------------------|----------------|--------------|---------|
| Root length (RL, cm)    | 195.65***      | 24.27***     | 18.66***|
| Root surface area (RSA, cm²) | 74.75***     | 9.86***      | 5.90*** |
| Root volume (RV, cm³)   | 29.25***       | 5.02**       | 2.18*   |
| Root diameter (RD, mm)  | 1.03           | 1.01         | 0.99    |
| Root dry weight (RDW, g) | 73.60***     | 5.68**       | 6.48*** |
| Shoot dry weight (SDW, g) | 38.18***    | 32.01***     | 3.82*** |
| Total dry weight (TDW, g) | 74.63***    | 30.59***     | 6.00*** |

Significant at *P<0.05, ** P<0.01, and *** P<0.001

Effects of cultivar, drought level and their interaction on root dry weight (RDW, g plant⁻¹) and shoot dry weight (SDW, g plant⁻¹)

RDW and SDW of almost cultivars were not significant different at the lower drought levels 5% PEG6000 compared with plants at 0% PEG6000, except for RDW in King grass (Fig. 3 and Fig. 4). Significant reductions were observed in RDW

Figure 3. Root dry weight (RDW, g plant⁻¹) of four cultivars under drought conditions. The treatments with different letters in each genotype are significantly different according to LSD-test at p< 0.05

Figure 4. Shoot dry weight (SDW, g plant⁻¹) of four cultivars under drought conditions. The treatments with different letters in each genotype are significantly different according to LSD-test at p< 0.05
and SDW of all cultivars at 10% PEG6000. In the comparison among cultivars, “Cô voi thuần” showed higher drought tolerance; while Packchong and King grass were drought-sensitive (Fig. 3 and Fig. 4).

**Effects of cultivar, drought level and their interaction on root traits**

Significant variations in root trait responses (RL, RSA, and RV) to drought level were found among cultivars (Fig. 5–7, Fig. 9, Table 2–4). Significance difference was not found in RD of cultivars under drought (Fig. 8, Table 5). Similar to RDW and SDW, “Cô voi thuần” showed higher drought tolerance; while Packchong and King grass were drought-sensitive (Table 2–4).

**DISCUSSION**

Napier grass distribution and accessions in various gene banks around the world has been reported [Negawo et al., 2017]. Genetic variation and Napier grass germplasm characterization using various kinds of DNA markers has been reported in several previous studies [Lowe et al., 2003, Kawube et al., 2015]. Similarly, morphological characterization of Napier grass has also been studied. Budiman et al. [2012] evaluated three Napier grass cultivars in regards to their above ground morphological characteristics, such as plant height, stem diameter and leaf stem ratio. However, there are fewer studies on variation on root performance under drought stress in Napier grass. In this study, four cultivars of Napier grass were evaluated for their root response to drought stress using polyethylene glycol 6000 (PEG6000) at 0% (control), 5%, 10%, 15% and 20% drought levels.

The obtained results indicated significant difference in root and shoot growth response to drought among the Napier grass cultivars (Table 1). The four Napier grass cultivars exhibited reduced root length growth as compared to control (0% PEG6000). Among the four cultivars; CVT exhibited the highest root length (RL), RSA and RV development at all drought levels, thus indicating drought-tolerance traits, while King grass and Packchong were drought sensitive (Tables 2, 3 and 4, Figure 3–5). The ability of Napier grass

### Table 2. Results of the two-way ANOVA for the effects of drought by cultivar interaction on root length (RL, cm) of Napier grasses

| PEG6000 | Cultivar    | Lsmean | SE  | Df  | Lower.CL | Upper.CL | .group |
|---------|-------------|--------|-----|-----|----------|----------|--------|
| 20%     | Packchong   | 55.2   | 38.9| 100 | -21.89   | 132      | a      |
| 20%     | King grass  | 71.6   | 38.9| 100 | -5.54    | 149      | ab     |
| 20%     | VA06        | 146.6  | 38.9| 100 | 69.50    | 224      | abc    |
| 15%     | King grass  | 243.1  | 38.9| 100 | 165.94   | 320      | abcd   |
| 15%     | Packchong   | 265.8  | 38.9| 100 | 188.70   | 343      | bcd    |
| 20%     | CVT         | 271.9  | 38.9| 100 | 194.81   | 349      | cd     |
| 15%     | VA06        | 391.0  | 38.9| 100 | 313.87   | 468      | d      |
| 15%     | CVT         | 630.5  | 38.9| 100 | 553.42   | 708      | e      |
| 10%     | Packchong   | 705.4  | 38.9| 100 | 628.24   | 782      | ef     |
| 10%     | King grass  | 864.7  | 38.9| 100 | 787.60   | 942      | fg     |
| 10%     | VA06        | 1009.0 | 38.9| 100 | 931.89   | 1086     | gh     |
| 5%      | King grass  | 1077.5 | 38.9| 100 | 1000.42  | 1155     | hi     |
| 0%      | VA06        | 1093.6 | 38.9| 100 | 1016.50  | 1171     | hi     |
| 10%     | CVT         | 1219.7 | 38.9| 100 | 1142.56  | 1297     | ij     |
| 5%      | VA06        | 1246.6 | 38.9| 100 | 1169.47  | 1324     | ij     |
| 0%      | CVT         | 1246.8 | 38.9| 100 | 1169.66  | 1324     | ij     |
| 5%      | Packchong   | 1379.7 | 38.9| 100 | 1302.62  | 1457     | jk     |
| 0%      | Packchong   | 1469.6 | 38.9| 100 | 1392.43  | 1547     | kl     |
| 0%      | King grass  | 1496.7 | 38.9| 100 | 1419.61  | 1574     | kl     |
| 5%      | CVT         | 1637.8 | 38.9| 100 | 1560.69  | 1715     | l      |

PEG6000 and Cultivar with different letters are significantly different according to Tukey’s honest significant difference test at P<0.05.
Table 3. Results of the two-way ANOVA for the effects of drought by cultivar interaction on root surface area (RSA, cm$^2$) of Napier grasses

| PEG6000 | Cultivar | Lsmean | SE  | Df  | Lower.CL | Upper.CL | .group |
|---------|----------|--------|-----|-----|----------|----------|--------|
| 20%     | Packchong| 4.19   | 4.92| 100 | -5.58    | 14.0     | a      |
| 20%     | King grass| 5.41  | 4.92| 100 | -4.36    | 15.2     | a      |
| 20%     | VA06     | 11.48  | 4.92| 100 | 2.07     | 21.6     | a      |
| 15%     | King grass| 18.36| 4.92| 100 | 8.60     | 28.1     | a      |
| 15%     | Packchong| 21.86| 4.92| 100 | 12.09    | 31.6     | a      |
| 20%     | CVT      | 22.51  | 4.92| 100 | 12.74    | 32.3     | a      |
| 15%     | VA06     | 29.06  | 4.92| 100 | 19.29    | 38.8     | ab     |
| 15%     | CVT      | 49.94  | 4.92| 100 | 40.17    | 59.7     | bc     |
| 10%     | Packchong| 58.06| 4.92| 100 | 48.29    | 67.8     | cd     |
| 10%     | King grass| 68.94| 4.92| 100 | 59.17    | 78.7     | cde    |
| 10%     | VA06     | 79.74  | 4.92| 100 | 69.97    | 89.5     | def    |
| 0%      | VA06     | 88.89  | 4.92| 100 | 79.12    | 98.7     | efg    |
| 5%      | King grass| 90.50| 4.92| 100 | 80.73    | 100.3    | efgh   |
| 0.1     | CVT      | 92.15  | 4.92| 100 | 82.38    | 101.9    | efgh   |
| 5%      | VA06     | 104.45 | 4.92| 100 | 94.68    | 114.2    | fghj   |
| 0%      | CVT      | 105.49 | 4.92| 100 | 95.72    | 115.3    | ghj    |
| 5%      | Packchong| 112.38| 4.92| 100 | 102.61   | 122.2    | ghj    |
| 0%      | King grass| 115.71| 4.92| 100 | 105.94   | 125.5    | hj     |
| 0%      | Packchong| 124.99| 4.92| 100 | 115.22   | 134.8    | j      |
| 5%      | CVT      | 127.38 | 4.92| 100 | 117.61   | 137.2    | j      |

PEG6000 and Cultivar with different letters are significantly different according to Tukey’s honest significant difference test at P<0.05.

Table 4. Results of the two-way ANOVA for the effects of drought by cultivar interaction on root volume (RV, cm$^3$) of Napier grasses

| PEG6000 | Cultivar | Lsmean | SE  | Df  | Lower.CL | Upper.CL | .group |
|---------|----------|--------|-----|-----|----------|----------|--------|
| 20%     | Packchong| 0.0256 | 0.05| 100 | 0.0-0.737 | 0.125     | a      |
| 20%     | King grass| 0.0329| 0.05| 100 | 0.0-0.663 | 0.132     | a      |
| 20%     | VA06     | 0.0766 | 0.05| 100 | 0.0-0.226 | 0.176     | ab     |
| 15%     | King grass| 0.1114| 0.05| 100 | 0.0-0.122 | 0.211     | ab     |
| 15%     | Packchong| 0.1435| 0.05| 100 | 0.0-0.443 | 0.243     | abc    |
| 20%     | CVT      | 0.1507 | 0.05| 100 | 0.0-0.0515 | 0.250     | abc    |
| 15%     | VA06     | 0.1755 | 0.05| 100 | 0.0-0.0762 | 0.275     | abc    |
| 15%     | CVT      | 0.3183 | 0.05| 100 | 0.0-0.2190 | 0.418     | bcd    |
| 10%     | Packchong| 0.3842| 0.05| 100 | 0.0-0.2850 | 0.483     | cde    |
| 10%     | King grass| 0.4448| 0.05| 100 | 0.0-0.3456 | 0.544     | def    |
| 10%     | VA06     | 0.5171 | 0.05| 100 | 0.0-0.4178 | 0.616     | defg   |
| 10%     | CVT      | 0.5559 | 0.05| 100 | 0.0-0.4567 | 0.655     | defgh  |
| 0%      | VA06     | 0.5805 | 0.05| 100 | 0.0-0.4813 | 0.680     | egf    |
| 5%      | King grass| 0.6078| 0.05| 100 | 0.0-0.5086 | 0.707     | egfhi  |
| 5%      | VA06     | 0.7020 | 0.05| 100 | 0.0-0.6028 | 0.801     | fghi   |
| 0%      | CVT      | 0.7164 | 0.05| 100 | 0.0-0.6171 | 0.816     | ghj    |
| 0%      | King grass| 0.7180| 0.05| 100 | 0.0-0.6188 | 0.817     | ghj    |
| 5%      | Packchong| 0.7325| 0.05| 100 | 0.0-0.6332 | 0.832     | ghj    |
| 5%      | CVT      | 0.7966 | 0.05| 100 | 0.0-0.6973 | 0.896     | hj     |
| 0%      | Packchong| 0.8550| 0.05| 100 | 0.0-0.7558 | 0.954     | i      |

PEG6000 and Cultivar with different letters are significantly different according to Tukey’s honest significant difference test at P<0.05.
Table 5. Results of the two-way ANOVA for the effects of drought by cultivar interaction on root diameter (RD, mm) of Napier grasses

| PEG6000 | Cultivar   | Lsmean | SE    | Df  | Lower.CL | Upper.CL | .group |
|---------|------------|--------|-------|-----|----------|----------|--------|
| 15%     | VA06       | 0.237  | 0.0115| 100 | 0.214    | 0.260    | a      |
| 10%     | CVT        | 0.240  | 0.0115| 100 | 0.217    | 0.263    | a      |
| 15%     | King grass | 0.242  | 0.0115| 100 | 0.219    | 0.265    | a      |
| 20%     | Packchong  | 0.242  | 0.0115| 100 | 0.219    | 0.265    | a      |
| 0%      | King grass | 0.245  | 0.0115| 100 | 0.222    | 0.268    | a      |
| 5%      | CVT        | 0.248  | 0.0115| 100 | 0.225    | 0.271    | a      |
| 10%     | VA06       | 0.252  | 0.0115| 100 | 0.229    | 0.275    | a      |
| 15%     | CVT        | 0.253  | 0.0115| 100 | 0.230    | 0.276    | a      |
| 10%     | King grass | 0.257  | 0.0115| 100 | 0.234    | 0.280    | a      |
| 0%      | VA06       | 0.257  | 0.0115| 100 | 0.234    | 0.280    | a      |
| 20%     | VA06       | 0.258  | 0.0115| 100 | 0.235    | 0.281    | a      |
| 5%      | Packchong  | 0.259  | 0.0115| 100 | 0.236    | 0.282    | a      |
| 15%     | Packchong  | 0.263  | 0.0115| 100 | 0.240    | 0.286    | a      |
| 10%     | Packchong  | 0.263  | 0.0115| 100 | 0.240    | 0.286    | a      |
| 20%     | CVT        | 0.265  | 0.0115| 100 | 0.242    | 0.288    | a      |
| 5%      | VA06       | 0.267  | 0.0115| 100 | 0.244    | 0.290    | a      |
| 5%      | King grass | 0.268  | 0.0115| 100 | 0.245    | 0.291    | a      |
| 0%      | CVT        | 0.268  | 0.0115| 100 | 0.245    | 0.291    | a      |
| 0%      | Packchong  | 0.270  | 0.0115| 100 | 0.247    | 0.293    | a      |

PEG6000 and Cultivar with different letters are significantly different according to Tukey’s honest significant difference test at P<0.05.

Figure 5. Root length (RL, cm) of four cultivars under drought conditions

to produce deep roots systems with large amounts of biomass has been previously reported [Sekiya et al., 2013]. These root morphological characters make Napier more tolerant to drought stress than other grass species, in addition to being C4 and perennial in nature [Purbajanti et al., 2012]. Thus, several researchers across the world have been involved in evaluating different Napier grass accessions for water use efficiency and productivity, and this has been mainly crucial in arid and semi-arid regions that are greatly affected by long-term droughts [Nyambati et al., 2010,
Figure 6. Root surface area (RSA, cm$^2$) of four cultivars under drought conditions.

Figure 7. Root volume (RV, cm$^3$) of four cultivars under drought conditions.

Figure 8. Root diameter (RD, cm$^3$) of four cultivars under drought conditions.
This study, therefore, indicates that Napier grass “Cỏ voi thuần (CVT)” could be an important genetic plant material resource for breeding of better Napier grass cultivars that are tolerant to drought and high yielding.

Higher development (as root branching and elongating) in root responses to water stresses is more advantageous to plant acquiring water but also nutrient uptake [Palta et al., 2011]. Packchong and King grass presented drought-sensitive cultivars with rapid decrease of RL and RSA. In addition, it was found that “Cỏ voi thuần (CVT)” was better adapted to drought as compared to the other cultivars. These results suggest that by a combined analysis of root plasticity and its association with water uptake and water use efficiency a more mechanistic understanding of factors involved in Napier root responses to drought will be reached and this should be the next research step.

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REFERENCES

1. Budiman, Sutrisno R.D., Budhi S.P.S., Indrianto A. 2012. Morphological characteristics, productivity and quality of three napier grass (Pennisetum purpureum Schum) cultivars harvested at different age, Journal of the Indonesian Tropical Animal Agriculture, 37, 294–301.
2. Cardoso J.A., Pineda M., Jiménez, de la C.L., Vergara, M.F., Rao I.M. 2015. Contrasting strategies to cope with drought conditions by two tropical forage C₄ grasses. AoB Plants, 7(107). DOI: doi.org/10.1093/aobpla/plv107
3. Comas L.H., Becker S.R., Cruz V.M., Byrne P.F., Dierig D.A. 2013. Root traits contributing to plant productivity under drought. Frontier in Plant Science, 4(442). DOI: 10.3389/fpls.2013.00442
4. Daryanto S., Wang L., Jacinthe P.A. 2016. Global synthesis of drought effects on maize and wheat production. PLoS ONE, 11, e0156362. DOI: 10.1371/journal.pone.0156362
5. Fang Y., Liang L., Liu S., Xu B., Siddique K.H.M., Palta J.A., Chen Y. 2021. Wheat cultivars with small root length density in the topsoil increased post-anthesis water use and grain yield in the semi-arid region on the Loess Plateau. European Journal of Agronomy, 124. DOI: 10.1016/j.eja.2021.126243
6. Farooq M., Wahid A., Kobayashi N., Fujita D., Basra S.M.A. 2009. Plant drought stress: effects, mechanisms and management. Agronomy for Sustainable Development, Springer Verlag/EDP Sciences/INRA, 2009, 29(1), 185–212. hal-00886451
7. Figueroa-Bustos V., Palta J.A., Chen Y., Stefanova K., Siddique K.H.M. 2020. Wheat cultivars with contrasting root system size responded differently to terminal Drought. Frontier in Plant Science, 11, 1285. DOI: 10.3389/fpls.2020.01285
8. Francini A., Sebastian L. 2019. Abiotic stress effects on performance of horticultural crops. Horticulturae, 5, 67. DOI: 10.3390/horticulturae5040067
9. Francini A., Sebastiani L. 2019. Abiotic stress effects on performance of horticultural crops. Horticulturae 5, 67.
10. Habte E., Muktar M.S., Teressa A., Lee K.W., Jones C.S. 2019. Identification of water use efficient Napier grass accessions using field drought stress. Post prepared for the International Conferences on Plant Breeding for Sustainable Development, Korea, 2–5 July 2019. Nairobi, Kenya: ILRI

11. Jabereidar A.A., El Naim A.M., Abdalla A.A., Yasin M., Dagash Y.M. 2017. Effect of water stress on yield and water use efficiency of sorghum (Sorghum bicolor L. Moench) in semi-arid environment. International Journal of Agriculture and Forestry, 7, 1–6. DOI: 10.5923/j.ijaf.20170701.01

12. Kabirizi J. Muyekho F., Mulaa M., Msangi R., Pallangyo B., Kawube G., Zziwa E., Mugerwa, S., Ajanga S., Lukwago G., Wamalwa N.I.E., Kariuki I., Mwesigwa R., Namyeena-Ntege, W., Atuhairwe A., Awalla J., Namazzi C., Namija Z. 2015. Napier grass feed resource: production, constraints and implications for smallholder farmers in Eastern and Central Africa. The Eastern African Agricultural Productivity Project, Naivasha, Kenya, 2015.

13. Kawube G., Alicai T., Wanjala B., Njahira M., Awalala J., Skilton R. 2015. Genetic diversity in Napier grass (Pennisetum purpureum) assessed by SSR markers. Journal of Agricultural Science, 7, 147.

14. Khan A., Pan X., Najeeb U., Tan D.K.Y., Fahad S., Zahoor R., Luo H. 2018. Coping with drought: stress and adaptive mechanisms, and management through cultural and molecular alternatives in cotton as vital constituents for plant stress resilience and fitness. Biological Research, 51, 47. DOI: 10.1186/s40659-018-0198-z

15. Kim Y., Chung Y.S., Lee E., Tripathi P., Heo S., Kim K.H. 2020. Root Response to Drought Stress in Rice (Oryza sativa L.). International Journal of Molecular Sciences, 21, 1513. DOI: 10.3390/ijms21041513.

16. Kim W., Iizumi T., Nishimori M. 2019. Global patterns of crop production losses associated with droughts from 1983 to 2009. Journal of Applied Meteorology and Climatology, 58, 1233–1244.

17. Küchenmeister K., Küchenmeister F., Kayser M., Wrage-Mönning N., Isselstein J. 2013. Influence of drought stress on nutritive value of perennial forage legumes. International Journal of Plant Production, 7, 693–710. https://www.sid.ir/en/journal/ViewPaper.aspx?id=339865

18. Lopes M.S., Araus J.L., van Heerden P.D., Foyer C.H. 2011. Enhancing drought tolerance in C4 crops. Journal of experimental botany, 62, 3135–3153. DOI: 10.1093/jxb/err105

19. Lowe A.J., Thorpe W., Teake A., Hanson J. 2003. Characterization of germplasm accession of napiergrass (Pennisetum purpureum and P. purpureum × P. glaucum hybrids) and comparison with farm clones using RAPD. Genetic Resources and Crop Evolution, 50, 121–132.

20. Lynch J.P., Chimungu J.G., Brown K.M. 2014. Root anatomical phenes associated with water acquisition from drying soil: targets for crop improvement. Journal of Experimental Botany, 65, 6155–6166. DOI: 10.1093/jxb/eru162

21. Meher, Shiviakrishna P., Ashok K.R., ManoharRao D. 2007. Effect of PEG-6000 imposed drought stress on RNA content, relative water content (RWC), and chlorophyll content in peanut leaves and roots. Saudi Journal of Biological Sciences, 25(2), 285–289.

22. Mwenda S., Yunusa I., Sindel B., Whalley D., Kariuki I. 2016. Assessment of Napier grass accessions in lowland and highland tropical environments in East Africa: productivity and forage quality. Experimental Agriculture, 53, 27–43.

23. Negawo A., Teshome A., Kumar A., Hanson J., Jones C. 2017. Opportunities for Napier Grass (Pennisetum purpureum) Improvement using molecular genetics. Agronomy, 7, 28. DOI: 10.3390/agronomy7020028.

24. Nguyen L.V, Bertero D., Long N.V. (2020). Genetic variation in root development responses to salt stresses of quinoa. Journal of Agronomy and Crop Science 206(2020) 538–547.

25. Nguyen N.T.A., Pham C.V., Nguyen D.T.N., Mochizuki, T. 2015. Genotypic variation in morphological and physiological characteristics of rice (Oryza sativa L.) under aerobic conditions. Plant Production Science, 18, 501–513. DOI: 10.1626/pps.18.501

26. Nguyen V.L., Takahashi R., Githiri S.M., Rodriguez T.O., Tsutsumi N., Kajihara S., Sayama T., Ishimoto M., Harada K., Suematsu K., Abiko T., Mochizuki T. 2017. Mapping quantitative trait loci for root development under hypoxia conditions in soybean (Glycine max L. Merr.), Theoretical and Applied Genetics, 130, 743–755.

27. Nyambati E.M., Muyekho F.N., Onginjo E., Lusweti C.M. 2010. Production, characterization and nutritional quality of Napier grass [Pennisetum purpureum (Schum.)]. African Journal of Plant Science, 4(12), 496–502.

28. Palta J.A., Chen X., Milroy S.P., Rebetzke G.J., Dreccer M.F., Watt M. 2011. Large root systems: are they useful in adapting wheat to dry environments? Functional Plant Biology, 38, 347–354. DOI: 10.1071/FP11031

29. Purbajanti, E.D., Anwar, S., Wydiati, Kusmiyati, F. (2012). Drought stress effect on morphology characteristics of rice (Oryza sativa) and napier grasses. International Research Journal of Agronomy and Crop Science, 3, 47–53.

30. Raza A., Razzaq A., Mehmood S.S., Zou X., Zhang X., Ly Y., Xu J. 2019. Impact of Climate Change on Crops Adaptation and Strategies to Tackle Its Outcome: A Review. Plants (Basel, Switzerland), 8(2), 34. DOI: 10.3390/plants8020034
31. Santos R., Carvalho M., Rosa E., Carnide V., Castro I. 2020. Root and agro-morphological traits performance in cowpea under drought stress. Agronomy, 10, 1604. DOI: 10.3390/agronomy10101604
32. Seleiman M.F., Al-Suhaibani N., Ali N., Akmal M., Alotaibi M., Refay Y., Dindaroglu T., Abdul-Wajid H.H., Battaglia M.L. 2011. Drought stress impacts on plants and different approaches to alleviate its adverse effects. Plants, 10(2), 259. DOI: 10.3390/plants10020259
33. Singh B.P., Singh H.P., Obeng E. 2013. Elephant grass. In: B.P. Singh, editor, Biofuel crops: Production, physiology and genetics. CAB Int., Fort Valley, GA. p. 271–291. DOI: 10.1079/9781845938857.0271
34. Wang C., Linderholm H., Song Y., Wang F., Liu Y., Tian J., Xu J., Song Y., Ren G. 2020. Impacts of drought on maize and soybean production in Northeast China during the past five decades. International Journal of Environmental Research and Public Health, 17, 2459. DOI: 10.3390/ijerph17072459
35. Wasaya A., Zhang X., Fang Q., Yan Z. 2018. Root phenotyping for drought tolerance: A Review. Agronomy, 8, 241. DOI: 10.3390/agronomy8110241
36. Yadav S., Modi P., Dave A., Vijapura A., Patel D., Patel M. 2020. Effect of abiotic stress on crops. In Sustainable Crop Production; Hasanuzzaman, M., Filho, M., Fujita, M., Nogueira, T., Eds, Intech Open, Rijeka, Croatia.
37. Zhang J., Zhang S., Cheng M., Jiang H., Zhang X., Peng C., Lu X., Zhang M., Jin J. 2018. Effect of drought on agronomic traits of rice and wheat: A Meta-Analysis. International Journal of Environmental Research and Public Health, 15, 839. DOI: 10.3390/ijerph15050839
38. Zhang R., Schellenberg M.P., Han G., Wang H., Li J. 2018. Drought weakens the positive effects of defoliation on native rhizomatous grasses but enhances the drought-tolerance traits of native caespitose grasses. Ecology and Evolution, 8, 12126–12139. DOI: 10.1002/ece3.4671.