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Morpho-physiological and Yield Responses of Sweet Potato (*Ipomoea batatas* (L.) Lam.) Genotypes to Frequency of Irrigation under Greenhouse Condition

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Authors' contributions

This work was carried out in collaboration between both authors. Author AGR designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author MT collected data, managed the analyses of the study and wrote the first draft of the manuscript. Both authors read and approved the final manuscript.

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ABSTRACT

Introduction: The sweet potato (*Ipomoea batatas* Lam.), is one of the root and tuber crops grown from low land to high land region of Ethiopia. However, its productivity depends on adaptability and tolerance to different environmental stresses and the capacity of the crop to enhance water use efficiency under moisture stress conditions. The objective of this study was to evaluate impact of irrigation interval on morpho-physiological characteristics of sweet potato varieties.
Methodology: The trial was a 3 x 2 factorial arrangement in CRD design consisting: three irrigation intervals (daily-control), four days and seven days interval) combined with two sweet potato genotypes (Hawassa-83 and Kulfo) with three replications.
Results: The morpho-physiological indicators, morphological traits, water use efficiency (WUE), Relative leaf water content (RLWC), leaf gas exchange, stomata density, and tuber yield were evaluated. The result indicated that morphological traits were significantly ($P \leq 0.05$) responded to genotype and irrigation frequencies. As compared to daily irrigation, an extended watering interval

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to seven days irrigation interval significantly reduced leaf number, vine length, branch number and internode length by 55.42, 19.83 cm, 2.17 and 0.35 cm, respectively. Stomata density was strongly responded to genotypes than effect of irrigation frequency. Genotype Hawassa-83 had approximately 2.0 more stomata per mm^2 than genotype Kulfo regardless to irrigation frequency. The interaction effect between genotype and irrigation frequency revealed significant influence on photosynthesis and transpiration rate. The rate of assimilate accumulation was significantly reduced (by 9.97μmol $m^{-2}s^{-1}$) in Hawassa-83 irrigated due to extended irrigation interval to seven days than variety irrigated daily. Delay irrigation for four and seven days reduced transpiration rate in genotype Hawassa-83 by 0.74 mmol $m^{-2}s^{-1}$ and 0.84 mmol $m^{-2}s^{-}1$, respectively. Result on WUE indicated that Kulfo was found better in efficiently utilizing water under extended irrigation interval than Hawassa-83. The leaf water content was significantly ($P \leq 0.001$) responded to irrigation frequency than genotypes. The higher leaf relative water content was obtained from daily irrigation than extended irrigation interval.

Conclusion: Finally it was observed that tuber yield under daily and four days irrigation interval was not statistically different in both varieties, This is therefore, the four days irrigation interval is recommended for sweet potato production from farmers economic point of view.

Keywords: Photosynthesis; stomata; genotype; WUE; sweet potato; tuber yield.

1. INTRODUCTION

Sweet potato (*Ipomoea batatas* L. Lam) is a dicotyledonous and tuberous root crop which belongs to the genus *Ipomoea* of the family *Convolvulaceae* that believed to be originated in the Central America (Norman et al. Among these approximately 50 genera and more than 1,000 species of Convolvulaceae, Some members of the family are weeds (e.g. hedge bindweed, *Convolvulus sepephum* L.) and ornamentals (e.g. morning glory, *Ipomoea purpurea* (L) Roth) [1] but *Ipomoea batatas* is the only crop plants of major importance as food [2,3]. Production of sweet potato in the world is about 106.5 million tons of tubers with a productivity of 4–6 MT/ha. In Ethiopia Sweet potato is the third most important root and tuber crops next to Enset (*Ensete ventricosum*) and potato in terms of area and total production. Even if it grows in most parts of the country at elevation from 1000 -2500 m.a.s.l altitude and (between 3-15ºN and 33-48ºE) latitude, 96 % of the production area is covered by the Southern Nations Nationalities People's Region State (SNNPRS) and Oromia region of Ethiopia. Sweet potato is used as human food, animal feed and human health and raw material for industrial production of starch, sugar and alcohol [4]. The yellow fleshed variety is a good source of beta-carotene, sources of vitamin A which are used to alleviate problem of night blindness of millions of children in sub-Saharan Africa including Ethiopia [5]. The wide range of variation in productivity can be related to difference in climatic factors including; UV-radiation, water stress, temperature, relative humidity, altitude as well as, crop genotype variation [6]. Sweet potatoes are often cultivated on non-irrigated lands and have been considered drought tolerant if some drought happen near the end of its life cycle [7,8]. However, soil moisture stress particularly at early growth stage is a crucial factor that limits its growth and development through affecting storage root production and yield [9]. In addition, water stress also causes a reduction in growth rate, stem elongation, leaf expansion and stomatal movements and changes in a number of physiological and biochemical processes governing plant growth and productivity [10]. Moreover, physiological and morphological process like water-use efficiency, growth performance and above-ground biomass of sweet potato are very sensitive to water stress and generally leads to loss of storage root's productivity [11]. In sweet potato, the function of stomatal closure and reduce CO_2 assimilation, under water deficit stress has been well studied, especially in the sensitive genotypes [12] and the stresses may cause a variety of plant responses which can be additive, synergistic or antagonistic[10].

Therefore, the purpose of this study was to investigate the effect of genotypes and irrigation interval and compare their effect and interaction on growth, physiology, yield and adaptive mechanism of two sweet potato varieties.

2. MATERIALS AND METHODS

2.1 Description of the Study Areas

The study was conducted at Hawassa, main campus of Hawassa University, under greenhouse condition, during September 2016 to March 2017. Hawassa is located at 7º04'N , and 38º31' E on the escarpment of the Great Rift valley with an elevation of 1700 meters above sea level, which is located about 275 km south of Addis Ababa, the capital city of Ethiopia. The mean annual rainfall and temperature of Hawassa are 900-1100 mm and 27ºC, respectively. The yearly average maximum and minimum temperature of the area was 26ºC and 12.4ºC, respectively. In general, the area receives short rainy season (March-May), "Belge" and long rainy season (July-October), "Meher".

2.2 Planting Materials and Description of the Genotypes

Two sweet potato genotypes known as Hawassa-83 and Kulfo were collected from Southern Agricultural research institute. They are well performing sweet potato genotype in terms of yield, nutritional value and under wide range of agro ecological conditions.

2.3 Experimental Design and Treatments

A factorial experiment with completely randomized design (CRD) with three levels of irrigation frequency (daily watering, four days interval and seven days interval) and two sweet potato genotypes (Hawassa-83 and Kulfo) was used to run the pot(pan) experiment under partially automated greenhouse condition. The pan was field with soil collected from field and air dried for three weeks so as to have a constant weight. Then after, a total of 90 experimental pots of 16.9 L volume, which accommodate 17.2 kg of soil per pans was filled with soil, which was calculated based on the bulk density of the soil. Tip cutting of each genotypes, 30 cm long, were planted directly in each pan.

2.4 Greenhouse Climate Condition

The greenhouse was partially automated to regulate temperature through side and roof ventilation system. During the experimental period (150 days) ambient air humidity was maintained through regulation of vents and manual irrigation system. Temperature and relative humidity data were recorded on randomly selected 25 days using mini data loggers (Testo 174, Version 5.0.2564.18771, Lenzkirch, Germany) (Fig. 1) during the experimental period from September to March, 2017. Data logger was hanged closer to the plant canopy (30cm above the ground) and covered from the top with flat carton to avoid direct sun and moisture The vapor pressure deficit of the greenhouse was calculated based on the temperature and relative humidity recorded using VPD-Auto grow software (www.autogrow.com/wp-content/uploads/2016/03/VPD_HDCALC.xls). Data were measured every hour for 25 days. Each point represents the average value of 25 days measurements.

From the result, it was observed that extremely higher (36.6℃) and lower (15.6℃) temperature was recorded during middle of the day (12:00am-1:00pm) and before dawn (5:00am to 6:00am), respectively (Table 2). However, the recorded average daily temperature of 24.9ºC is the optimal temperature for vegetative and tuber production for most of sweet potato genotypes [14,15].

Regarding to relative humidity, greenhouse daily maximum relative humidity (66.3%) was recorded at 5:00am which was coincided with greenhouse minimum temperature (15.6%) and minimum vapor pressure difference (0.60KPa). Likewise, greenhouse daily minimum relative humidity (22.8%) was recorded at 1:00pm which coincided with maximum daily temperature (36.6%) and maximum daily vapor pressure deficit (4.74KPa).

2.5 Soil Sampling, Preparation and Analysis

Composite soil sample, made from twelve sub-samples, was collected from Hawassa University research field in a diagonal pattern from 0-20 cm soil depth. The samples were air-dried, ground to pass through a 2 mm sieve, except for analysis of organic carbon, where the samples were passed through 0.5 mm sieve. Working samples were obtained from each submitted samples and analyzed for selected Physico-chemical properties such as texture, soil pH, and organic carbon, using standard laboratory procedures at Hawassa University, College of Agriculture, Plant and Soil Analysis Laboratory. Organic carbon content of the soil was determined by reduction of potassium dichromate and oxidation reduction titration with ferrous ammonium [16]. Soil particle size distribution was determined by hydrometer method (differential settling within a water column) using particles less than 2 mm diameter. The pH of the soil was measured in 1:2.5 (weight/volume) soil samples to $CaCl_2$ solution ratio using a glass electrode attached to digital

Table 1. Description of varieties used for the experiment

Variety	Altitude (m.a.s.l)	Maturity (days)	Flesh color	Yield tone/ha	Years of release
Hawassa-83	1500-2500	150-180	White	36.6	1998
Kulfo	1200-2000	150	Orange	31.5	2005

Source: [13]

Table 2. Greenhouse daily climatic variables recorded during the experiment period on randomly selected days (Average of 25 days)

Hour	Temperature (℃)	Relative humidity (%)	VPD (KPa)
13:00 pm	36.6	22.8	4.74
14:00 pm	35.7	23.2	4.49
15:00 pm	33.5	23.4	3.96
16:00 pm	31.8	24.7	3.54
17:00 pm	27.5	30.3	2.56
18:00 pm	24.3	38.1	1.88
19:00 pm	22.9	44.0	1.56
20:00 pm	21.9	47.5	1.38
21:00 pm	21.0	49.1	1.27
22:00 pm	20.1	51.4	1.14
23:00 pm	19.3	53.6	1.04
24:00 pm	18.6	56.7	0.93
1:00 am	18.0	59.2	0.84
2:00 am	17.3	61.8	0.75
3:00 am	16.6	62.7	0.70
4:00 am	16.1	64.6	0.65
5:00 am	15.6	66.3	0.60
6:00 am	15.9	66.0	0.61
7:00 am	21.7	52.6	1.23
8:00 am	27.4	40.3	2.18
9:00 am	31.3	32.5	3.08
10:00 am	33.8	27.7	3.80
11:00 am	35.0	26.5	4.13
12:00 am	36.5	24.2	4.65

Note: VPD = Vapor pressure difference and KPa = Kilo Pascal

pH meter. Organic matter and total nitrogen was obtained by derivation from soil organic carbon content. Moreover, in order to determine the bulk density of the soil, actual moisture content, and moisture content at field capacity, twelve soil samples were taken from experimental soil by using soil core sampler and determined using gravimetric method at Melka Werer Agricultural Research Center.

The results of the physical and chemical properties of the soil of the study site were presented in Table 3. The analysis indicated that soil texture, level of organic carbon, total nitrogen and soil moisture were found to the recommended growing media quality [17,18] and the actual soil moisture content of the soil and moisture content at field capacity were 29.7% and 35.5%, respectively (Table 3).

Table 3. Selected physical and chemical properties of the experimental soil collected from the study area

Physical and chemical properties	Values
pH	7.6
Soil texture	Loam
Bulk density (g/cm^3)	1.018
Organic matter (OM %)	5.4
Organic carbon (OC %)	3.1
Total nitrogen (%)	0.11
Moisture content at FC (v/v %)	35.5
Soil moisture content (v/v %)	29.7

2.6 Plant Growth Parameters

During the experimental periods (60 days after the start of the treatments) nondestructive sampling for vine length, number of leaves, branch number (>2 cm), internode length, were recorded from two plants in ach treatments. At 60 days after the start of the treatments destructive sampling were carried out to measure total leaf area, specific leaf area (SLA), and Leaf Area Ratio (LAR) (the ratio of leaf area and total plant weight) per plant. A LI-3100 leaf area meter (LI-COR, Inc., Lincoln, Nebraska, USA) was used to measure total leaf area. Moreover, leaf dry weight was determined after drying the leaves at 70℃ for 48 hours and specific leaf area was calculated (SLA= leaf area/leaf dry mass (cm^2g^{-1}). At the age of 60 days after the start of the treatment, the leafiness of the plant was determined by calculating the leaf area ratio (LAR) which is expressed in cm^2g^{-1} of plant dry weight.

2.7 Stomata Density

Two Sweet potato plants with intact root from each treatment were used for the measurement of stomata density at 60 days after the start of the treatment. Epidermal impressions were made on fresh intact lower leaves of the two genotypes following the procedure of Torre et al. [19]. Stomata number was counted using Automated Upright Leica Microscope DM5000 B, fixed with digital Leica DFC425/DFC425C image processing camera.

2.8 Photosynthesis and Gas Exchange Parameters

Photosynthesis(A), Transpiration rate (E) and Stomata conductance (g_s) were measured during the vegetative stage at 60 days after the start of the treatment on fully developed intact leaves at the 5th node using an open system LCA-4 ADC portable infrared gas analyzer (Analytical Development Company, Hoddeson, England). These measurements were done between 12:00 and 15:00 h with the following specifications/adjustments: Leaf surface area was 6.25 cm^2, ambient carbon dioxide concentration 340 µmol mol^{-1}, temperature of the leaf chamber varied from 34 to 47°C, leaf chamber molar gas flow rate was 410 µmol s^{-1}, ambient pressure 828 mbar and photosynthetic active radiation (PAR) at the leaf surface was maximum up to 1500 µmol m^{-2} s^{-1}. Data was collected every five min for 15 min using three leaves in each of 3 plants per treatment.

2.9 Instantaneous Water Use Efficiency (IWUE)

The ratio of carbon gain in photosynthesis and loss of water in transpiration was calculated based on the data generated by open system LCA-4 (LCA-4 Software Version 1.04) ADC portable infrared gas analyzer used at the growth stage of 60 days after the start of the treatments. The ratio of leaf photosynthesis (A) to leaf transpiration rate (E) indicates the efficiency of the genotype to produce dry matter per water loss through the leaves.

2.10 Leaf Relative Water Content (LRWC)

Leaf relative water content was measured using the method of Kamara et al. [20]. Leaf discs (10 mm in diameter) were taken from young fully expanded leaves at 60 days after the start of the treatment in the field sealed in tubes. The tubes containing leaf samples were immediately placed on ice box which was not frozen, and immediately brought to the laboratory. Leaf discs that were cut from the leaves were directly weighed to determine fresh weight (FW). Samples were then floated in 100ml of distilled water in a closed Petri dish under low light (50µmol m-2s-1) for 24 hours. Leaf samples were taken out of water and were surface dried with tissue paper, and their turgid weights (TW) were recorded. The leaf relative water content takes into account the turgid mass of leaves, and so it is the proportion of the leaf water content related to the maximum water content that can potentially be achieved by the leaf. The samples were packed in paper bags, and oven dried at 65^{o}C for 48 hours for dry weight (DW) determination. The leaf discs were weighed using an analytical balance with precision of 0.00001 g. Then calculation of leaf relative water content was computed as following the methodology of Turner [21]:

$$\text{LRWC (\%)} = \frac{\text{FW}-\text{DW}}{\text{TW}-\text{DW}} \text{ x } 100$$

2.11 Dry Matter Accumulation and Tuber Yield

At harvesting time; leaf, vine plus petiole, root and tuber components were taken from three plants and weighed separately. The tubers were washed to remove soil and allowed surface air dried for approximately 30 minutes, and weighed to obtained fresh weight. Each plant part was allowed to dry for 48 hours in an oven at 70ºC.

2.12 Harvest Index (HI)

At harvest, 152 and 168 days after planting for genotype Kulfo and Hawassa-83 respectively, a pan area of within each treatment of sweet potato genotypes was harvested (0.1125 m^2), and whole plant part with in the pan was oven dried up to a constant weight, weighed and then converted into biological yield (biomass) (g/m^2). The harvested bottom part (tuber) is considered as economic yield (tuber yield in g / m^2). Harvest index was calculated according to the following the methodology of Ludlow and Muchow [22]:

Harvest index (%) = (tuber yield / Biological yield) × 100.

2.13 Statistical Analysis

Analysis of variance (ANOVA) was carried out using SAS statistical software version 9.00 (SAS Institute, 2002). Mean separation was done by using Tukey's procedure ($P \leq 0.05$). When there was a statistically significant interaction between the factors, the interaction was considered, rather than the main effects, otherwise, only the main effects of treatments was presented. Pearson's simple correlation coefficient was used to analyze correlation between selected parameters.

3. RESULTS AND DISCUSSION

3.1 Morphological Characters

3.1.1 Vine length, leaf number, branch number and internode length

The result indicated that leaf number, branch number and vine length were significantly ($P\leq0.05$) responded to genotype and irrigation frequencies. Result in Table 4 indicated that, vegetative growth was more enhanced in Kulfo than Hawassa-83. Although genotype has been contributing to the differences in growth performance of the plant, prolonged irrigation interval (more than a day) showed stronger effect on vegetative growth. The longer the irrigation interval (lower irrigation frequency), the more the reduction was observed in vegetative growth in both genotypes.

Analysis of variance revealed that as compared to daily irrigation an extended watering interval to seven days significantly reduced leaf number, vine length, branch number and internode length by 55.42, 19.83 cm, 2.17 and 0.35 cm respectively (Table 4).

The result is in agreement with the finding of Sokoto and Gaya [23] who reported significantly less number of leaves under lower irrigation frequency on sweet potato. On the other hand, vine length reduction under lower irrigation frequency has also been reported in many other crop species. Previous research [24] found that the main length of harvested shoot of rose during the period of measurements irrigated with high frequency produced slightly longer stems than those irrigated with low frequency. Moreover, Laurie and Magoro [25] also reported that reduction in vine length of sweet potato has been positively correlated to the decline in irrigation rates from 100% full irrigation to 30% irrigation. Similar to the present study, Ebel et al. [26] found that an extended irrigation interval led to decrease in percentage of vine length in sweet potato. Branch number was also found to be significantly reduced when extended irrigation interval was considered. Report from [27,28] noted that number of branches per plant were significantly influenced under water stress condition.

The former author reported that when water was withheld, the inter node length of sweet potato cultivars found to be significantly declined. This is mainly due to decrease in turgor pressure within cells during cell growth and development forcing the inhibition of cell expansion which could in turn reflected in decrease in internode length, leaf number and vine length. This probably could be one of the adaptation strategies in plants against moisture stress to minimize potential water loss from the surface of the plant.

3.1.2 Total leaf area

Total leaf area production per plant was significantly affected by the interaction effect of genotype and irrigation frequency. Result on Fig. 1 showed that, total leaf area was significantly ($P\leq0.05$) influenced by interaction between genotype and irrigation frequency. Maximum leaf area was obtained when Hawassa-83 was irrigated daily than Kulfo. As compared to daily irrigation, extending irrigation interval to four days and seven day significantly reduced leaf area 553 cm^2 (Hawassa-83and 438 cm^2 (Kulfo) and 1139.5 cm^2 (Hawassa 83) and 709 cm^2 (Kulfo), respectively (Fig 1). This indicated that Hawassa-

83 was more sensitive to moisture stress than Kulfo genotype and adaptation to moisture stress was largely observed in kulfo than Hawassa-83 genotype.

As Meyer and Boyer [29] stated that the occurrence of water deficits in young growing plants would also be expected to cause a reduction in cell turgor which would slow leaf expansion and growth. These observations are supported by previous findings reporting reduction in leaf area under decreasing soil water regimes to 40% and 20% of the field capacity significantly reduce leaf production compared to growth under well-watered conditions [30]. Our results show that, specific leaf area and leaf area may have a higher plasticity in response to a large range of water status, and these parameters are clearly associated with photosynthesis and water use efficiency.

Table 4. Main effects of genotype and irrigation frequency on Leaf Number (LN), Vine-Length (VL), Branch Number (BR) and Internode Length (INL)

Treatments	Leaf number	Vine length (cm)	Branch number	Internode length (cm)
Genotype				
Hawassa-83	85.61[b]	73.42[b]	5.92[b*]	1.66
Kulfo	203.83[a]	106.89[a]	7.98[a]	1.53
Tukey's $HSD_{(0.05)}$	33.231	7.167	0.3681	Ns
Irrigation frequency(I)				
Daily watering	164.25 [a]	101.21 [a]	8.13 [a]	1.80 [a]
Four days interval	161.08 [a]	87.88 [b]	6.75 [b]	1.53 [b]
Seven days interval	108.83 [b]	81.38 [b]	5.96 [c]	1.45 [b]
Tukey's $HSD_{(0.05)}$	49.833	10.748	0.5521	0.2186
F test values				
Genotype (G)	60.08[***]	103.55 [***]	148.00 [***]	3.78 [ns]
Irrigation frequency (I)	5.55[*]	12.60[**]	56.14[***]	10.18[**]
G x I	3.81[ns]	1.06 [ns]	3.76 [ns]	0.84 [ns]
SEM ±	26.42	5.70	0.45	0.12
CV (%)	22.36	7.74	5.16	8.9

**Means in the same column followed by the same letter are not significantly different at the 5% probability level*

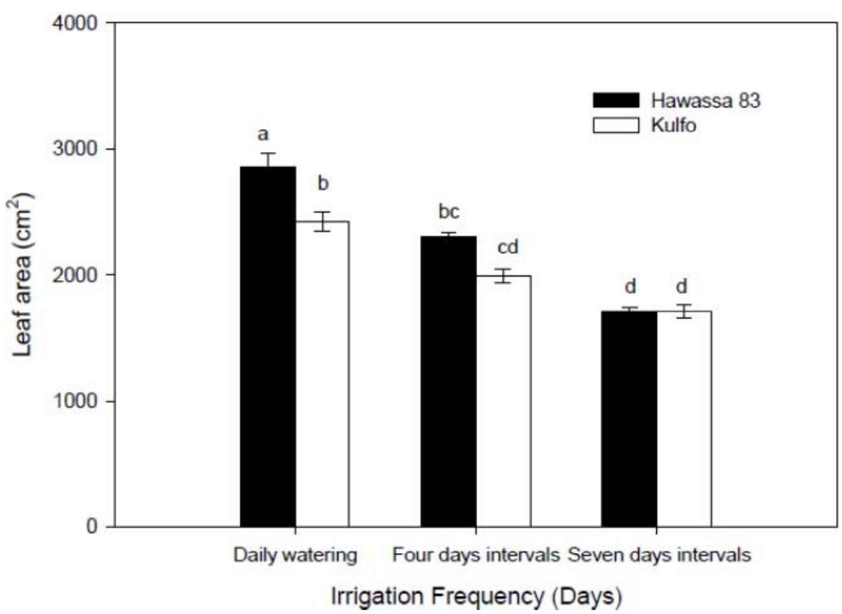

Fig. 1. Illustration of genotypes response to irrigation frequency on leaf area (cm^2). Error bars represent standard errors of means with three replications. Means with same letter (s) are not significantly different at p ≤ 0.05

Table 5. Effect of genotype and irrigation frequency on stomata density (SD), Specific Leaf Area (SLA) and Leaf Area Ratio (LAR) of sweet potato grown under greenhouse

Treatments	SD(mm^2)	SLA(cm^2g^{-1})	LAR (cm^2g^{-1})
Genotype			
Hawassa-83	16.06^a	245.87^{a*}	46.22^a
Kulfo	14.54^b	222.71^b	39.37^b
Tukey's $HSD_{(0.05)}$	0.7744	12.244	5.0898
Irrigation frequency			
Daily watering (control)	15.42	246.60^a	44.50
Four days interval	15.78	225.22^b	44.79
Seven days interval	14.70	231.05^{ab}	39.09
Tukey's $HSD_{(0.05)}$	Ns	18.361	Ns
F-test values			
Genotype (G)	18.29^{***}	16.98^{**}	8.58*
Irrigation frequency (I)	3.21^{ns}	5.16^{*}	2.52^{ns}
G x I	0.05^{ns}	3.44^{ns}	1.67^{ns}
SEM ±	0.62	9.73	4.05
CV (%)	4.93	5.09	11.58

**Means in the same column followed by the same letter are not significantly different at the 5% probability level*

3.2 Physiological Characteristics

3.2.1 Leaf anatomy and stomata density

Result indicated that irrigation frequency did not show significant differences (P > 0.05) on stomata density per mm^2.However, stomata density was significantly influenced due to genotype effect. From the analysis it was observed that genotype Hawassa-83 had approximately 2.0 more stomata number per mm^2 than genotype Kulfo (Table 5). Although irrigation did not have significant effect on density of stomata, result on Table 5 indicated that delaying irrigation by seven days reduced density of stomata per mm^2 than plant irrigated daily or every four days interval.

The result verified with findings of Saraswati [30] who noted that stomatal density of sweet potato cultivars was unaffected by soil water stress conditions. However, in this study there was significant variation between genotypes considered. This might be related to the variability in genetic make-up of the genotypes. Previous report indicated that, an increase in stomata density under water deficit, indicated that an adaptation to moisture stress vary from genotype to genotype [31,32].

3.2.2 Specific Leaf Area (SLA) and Leaf Area Ratio (LAR)

The main effects of genotype and irrigation frequency was significant (P ≤ 0.05) on specific leaf area (SLA). Irrigation at four days interval significantly (P ≤ 0.05) reduced SLA by 9% compared to the daily irrigation in both genotypes. Regarding genotypes, Kulfo had significantly (P ≤ 0.01) superior performance over genotype Hawassa-83, implying that genotype Kulfo possibly had thicker leaves than genotype Hawassa-83 (Table 5). Unlike, LAR was not significantly (P > 0.05) affected by different irrigation frequencies. The highest and least LAR was observed from daily irrigation and followed by seven days interval respectively, although it was statistically at par with (Table 5). However, different genotypes showed significant (P ≤ 0.05) difference in LAR. Genotype Hawassa-83 had better performance in leaf area ratio than Kulfo, this implies that genotype Hawassa-83 was leafy (Table 5).

3.2.3 Photosynthesis (A)

The highest assimilation rate was produced from the interaction between genotype Hawassa-83 and daily irrigation followed by Kulfo by seven days interval, while the least assimilation rate was observed from Hawassa-83 by seven days interval. There was significant difference in the rate of assimilate due to the interaction between genotype and irrigation intervals. The highest amount of assimilation rate (16.16 μmol $m^{-2}s^{-1}$) was produced from genotype Hawassa-83 treated with daily irrigation (Fig. 2). However, there was no significance difference in the rate of assimilation between Hawassa-83 genotype irrigated every day and four day interval. In this study it was observed that water extended water holding for seven days significantly reduced assimilation rate by 9.97µmol m-2s-1 compared to Hawassa-83 treated with daily irrigation. Genotype Kulfo had produced statistically similar assimilation rate over the entire irrigation frequency considered in this trial (Fig. 2).

Result indicated that genotype Hawassa-83 has shown strong reduction in assimilation rate as irrigation interval prolonged. Quite in opposite, genotype Kulfo had stable performance across irrigation frequencies. This might imply genotype Hawassa-83 was more sensitive to moisture stress than genotype Kulfo. In line with this study, Shao et al. [33] noted that, as the soil water availability declines, leaf cells lose their turgor; this affects the leaf photosynthesis due to stomatal closure and physical disruption of the leaf cells. Moreover, report indicated that, higher irrigation frequency increased g_s and with high g_s values favored CO_2 assimilation and plants showed higher daily carbon gain on tomato [34].

3.2.4 Transpiration rate (E)

The results of interaction effect between genotype and irrigation frequency showed significant ($P \leq 0.05$) effect on transpiration rate, though it was not large enough to be extremely different from main effects. Nonetheless, the highest rate of transpiration (3.81 mmol $m^{-2}s^{-1}$) was recorded when genotype Kulfo was irrigated daily whereas the least (2.17 mmol $m^{-2}s^{-1}$) was observed from genotype Kulfo and seven days irrigation interval (Fig. 3). In contrast, withholding irrigation for four days or seven days significantly reduced transpiration rate in both genotypes (Hawassa-83 and Kulfo) as compared to treating both genotype with daily irrigation. Consequently, four and seven days delay in irrigation significantly reduced transpiration rate in genotype Hawassa-83 by 0.74 mmol $m^{-2}s^{-1}$ and 0.84 mmol $m^{-2}s^{-1}$ respectively. And stronger decline in transpiration rate were observed when genotype Kulfo was irrigated with four and seven days irrigation intervals with 1.14 mmol $m^{-2}s^{-1}$ and 1.66 mmol $m^{-2}s^{-1}$ reductions, respectively (Fig. 3).

Overall, genotype Kulfo combined with daily irrigation gave significantly higher transpiration rate. The reduction in the rate of transpiration with decrease in the rate of irrigation might be associated with lower number of stomata density in genotype Kulfo, which finally attributed to have relatively lower transpiration rate under extended watering interval. Parallel with the result report from Garnier et al. [35] indicated that tolerance in drought in different plant species associated with lower number of stomata and reduction in the rate of water lost which attributed to its capability to maintain cellular integrity by conserving water under drought conditions. Saraswati [30] also reported that water stressed plants transpired less water compared to the well-watered plants in sweet potato cultivars. In addition, one of the adaptive features of plants growing in drought

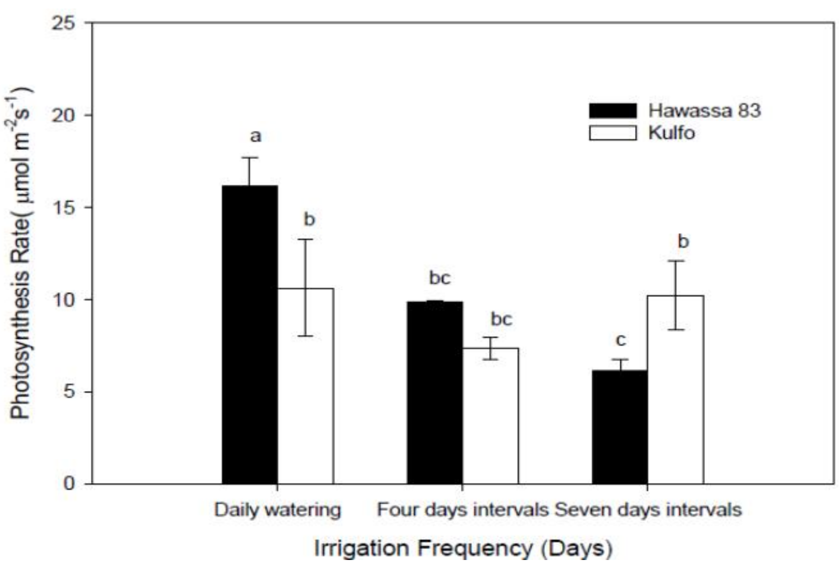

Fig. 2. The interaction effects of genotype and irrigation frequency of sweet potato on photosynthesis (µmol m^{-2} s^{-1}). Means with same letter (s) are not significantly different at $p \leq 0.05$

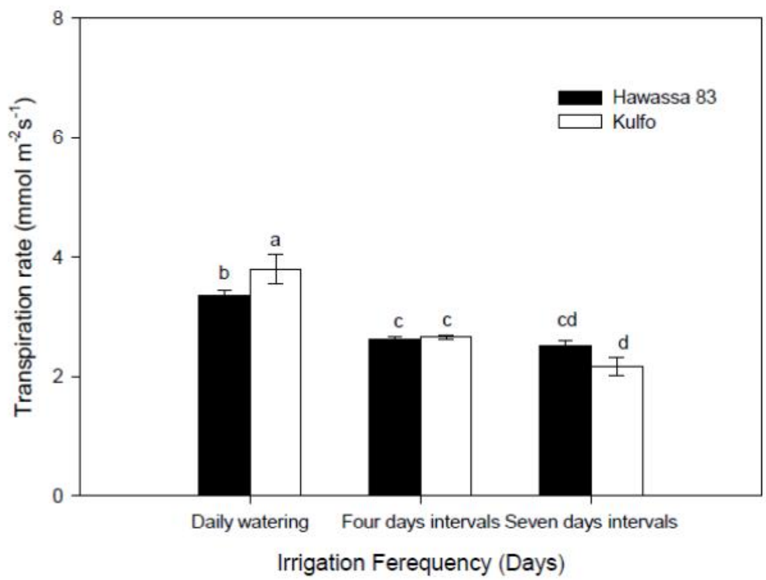

Fig. 3. Illustration of response of sweet potato genotypes as influenced by irrigation efficiencies on transpiration rate ($mmol^{-2}s^{-1}$). Means with same letter (s) are not significantly different at $p \leq 0.05$

Table 6. Main effects of genotype and irrigation frequency on stomatal conductance (g_s) in mmol m-2s-1

Treatments	gs ($mmolm^{-2}s^{-1}$)
Genotype	
Hawassa-83	110.0^{a*}
Kulfo	100.0^{a}
Tukey's $HSD_{(0.05)}$	Ns
Irrigation Frequency	
Daily watering (control)	143.3^{a}
Four days interval	91.7^{b}
Seven days interval	80.0^{b}
Tukey's $HSD_{(0.05)}$	0.0254
F-test values	
Genotype (G)	1.65^{ns}
Irrigation frequency (I)	25.04^{***}
G x I	2.39^{ns}
SEM ±	0.01
CV (%)	15.71

**Means in the same column followed by the same letter are not significantly different at the 5% probability level*

condition is reduction in the size of stomata opening and leaf size to reduce loss of moisture through transpiration.

3.2.5 Stomatal conductance (g_s)

The main effects of irrigation frequency showed significant ($P \leq 0.001$) effect on stomatal conductance (g_s). The highest stomatal conductance was obtained in response to daily watering followed by four days interval while the least was observed from seven days interval. As compared to the effect of daily irrigation, genotypes treated to four and seven days water holding significantly reduced Stomatal conductance by 51.6 mmol $m^{-2}s^{-1}$ and 63.3 mmol $m^{-2}s^{-1}$, respectively (Table 6). Unlike, there was no significant ($P > 0.05$) difference between genotype in relation to stomatal conductance.

The difference in stomata conductance might be associated to dry out of soil and the leaf water potential that play significant role in influencing the stomatal conductance [36]. Previous report indicated that a severe decline in stomatal conductance values for sweet potato plants subjected to drought stress. Yooyongwech et al. [37] also noted that stomatal conductance (g_s) in sweet potato genotypes declined significantly when plants were subjected to mild and extreme water deficit stress.

3.2.6 Instantaneous Water Use Efficiency (IWUE)

The analysis of variance revealed that there was statistically significant ($P \leq 0.001$) differences in IWUE due to the interaction effect between genotype and irrigation interval. The interaction of genotype Kulfo and seven days interval resulted with the highest instantaneous water use efficiency as compared to genotype Hawassa-83 (Fig. 4). In response to genotype by irrigation frequency, extended watering interval for seven days with genotype Hawassa-83 had significant reduction (i.e., by 2.32 IWUE) compared to the combination of genotype Hawassa-83 and daily irrigation (Fig. 4). On the other hand, higher irrigation frequency of daily and four days watering intervals resulted in significant reduction on genotype Kulfo in instantaneous water use efficiency with 3.33 IWUE and 3.42 IWUE, respectively over genotype Kulfo which was irrigated with seven days irrigation interval (Fig. 4).

Result indicated that, under seven days irrigation interval, genotype Kulfo was able to conserve and utilize water efficiently than Hawassa-83. This was attributed to low transpiration rate as a result of small leaf surface area, and few stomata density. Quite in opposite, genotype Hawassa-83 responded differently to irrigation frequency suggesting that sweet potato genotypes had different response to irrigation interval. Nevertheless, in this study the highest IWUE was observed from the interaction between Kulfo and seven days interval. This result supported with the finding of Kang and Wan [38] who noted that water use efficiencies of radish was significantly increased by decreasing irrigation level. Moreover, Pires et al. [34] reported that the highest IWUE values were noticed in plants subjected to high irrigation frequency than to low irrigation frequency on tomato.

3.3 Leaf Relative Water Content

Sweet potato significantly (P ≤ 0.001) responded to different irrigation frequency on leaf relative water content. The higher leaf relative water content was obtained from daily irrigation whereas the lowest was observed from seven days interval. Unlike, seven days interval had significant deviation on leaf relative water content from daily irrigation. In quantitative term seven days interval recorded 9.99% reduction compared to the daily irrigation (Table 7). Regarding on genotype difference, there was no significant variation in leaf relative water content between Hawassa-83 and Kulfo (Table 7).

Leaf relative water content was substantially diminished when sweet potato genotypes were subjected to prolonged irrigation frequency (seven days interval). Under extended irrigation interval tissues and cells were not well hydrated enough (lower LRWC%) which might have an impact on normal physiological activities. In line with this, Saraswati [30] indicated that water stress caused significance decease in the relative water content in sweet potato. Under lower soil field capacity, the leaf relative water content declined compared to that of the same cultivars grown at higher soil field capacity.

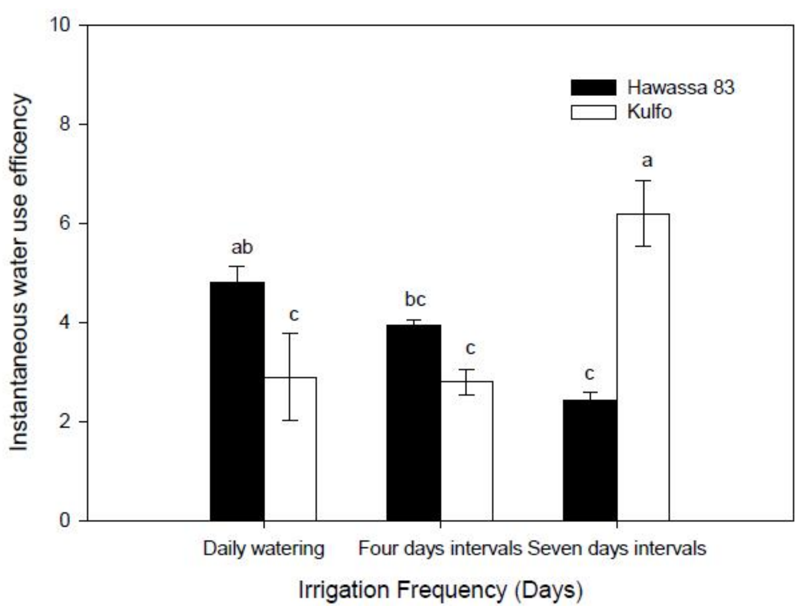

Fig. 4. The interaction effect of genotype and irrigation frequency on instantaneous water use efficiency (μmol mmol^{-1}). Means with same letter (s) are not significantly different at p ≤ 0.05

Table 7. The main effects of genotype and irrigation frequency on Leaf Relative Water Content (LRWC)

Treatments	LRWC (%)
Genotype	
Hawassa-83	61.73[a*]
Kulfo	64.20[a]
Tukey's $HSD_{(0.05)}$	Ns
Irrigation Frequency	
Daily watering (control)	67.67[a]
Four days interval	63.55[a]
Seven days interval	57.68[b]
Tukey's $HSD_{(0.05)}$	4.1771
F-test values	
Genotype (G)	4.9[ns]
Irrigation frequency (I)	27.17[***]
G x I	0.03 [ns]
SEM ±	1.57
CV (%)	3.06

**Means in the same column followed by the same letter are not significantly different at the 5% probability level*

3.4 Yield and Yield Components

3.4.1 Dry mass production, biomass yield, tuber yield and harvest index

The interaction effect of genotype and irrigation frequency showed non-significant (P > 0.05) effect on leaf dry mass and root dry mass production. Quite in reverse, storage root dry mass was significantly influenced by the interaction effect of genotype and irrigation frequency. The main effect of irrigation frequency and genotype were found to be significant on root dry mass and leaf dry mass of sweet potato except for main effect of genotype on leaf dry mass. Significantly (P ≤ 0.01) maximum leaf dry mass accumulation was observed from daily irrigation. Comparatively, irrigating in seven days interval had recorded significantly reduced performance by 2.91gm over the daily irrigation in leaf dry mass (Table 8). In contrast, concerning the genotype difference for leaf dry mass accumulation, there was no significant variation between genotype Hawassa-83 and genotype Kulfo (Table 8).

Root dry mass was also significantly (P ≤ 0.01) affected by irrigation frequency (Table 8). It was observed that irrigating the genotype in every seven days interval gave the highest root dry mass and found to be significantly different from daily irrigation with 1.67 gm (Table 8). On the other hand, irrigation frequency treatment, which was irrigated once in every four days interval, was statistically at par with daily irrigation for root dry mass accumulation. Regarding on root dry weight accumulation genotype Hawassa-83 had accumulated significantly (P ≤ 0.001) higher (2.29gm) dry mass than sweet potato genotype Kulfo (Table 8).

Report from Saraswati [30] indicated that water stress significantly reduced dry leaf masses of different sweet potato cultivars. However, in this

Table 8. Main effects of root dry weight (RDM) and leaf dry weight (LDM) of sweet potato as influenced by genotype and irrigation frequency

Treatments	RDM(g)	LDM(g)
Genotype		
Hawassa-83	4.83[a*]	7.26[a]
Kulfo	2.54[b]	6.13[a]
Tukey's $HSD_{(0.05)}$	0.6063	Ns
Irrigation frequency		
Daily watering (control)	2.83[b]	8.20[a]
Daily watering control	2.83[b]	8.20[a]
Four days interval	3.73[ab]	6.60[ab]
Seven days interval	4.50[a]	5.29[b]
Tukey's $HSD_{(0.05)}$	0.9092	1.7732
F test values		
Genotype (G)	67.98[***]	4.30 [ns]
Irrigation frequency (I)	11.98[**]	9.58[**]
G x I	2.72[ns]	0.41[ns]
SEM ±	0.48	0.94
CV (%)	16.01	17.19

**Means in the same column followed by the same letter are not significantly different at the 5% probability level*

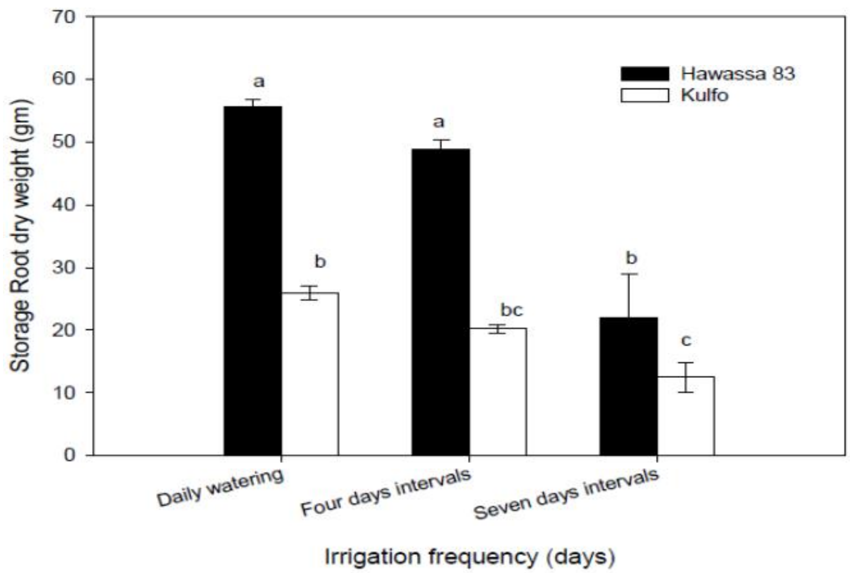

Fig. 5. The interaction effect of genotype and irrigation frequency of sweet potato on storage root dry mass. Error bars represent standard errors of means with three replications. Means with same letter (s) are not significantly different at p ≤ 0.05

study we investigated that reduction in irrigation frequency increased root dry mass than frequently irrigated genotypes.

3.4.2 Storage root dry mass

ANOVA analysis indicated that the interaction between genotype and irrigation frequency showed significant (P ≤ 0.05) influence on storage root dry mass. Higher storage root dry mass accumulation was found from Hawassa-83 and daily irrigation than kulfo under similar growth condition. It was observed that reduction in irrigation frequency significantly reduced storage root dry mass from 6.66 gm to 33.34gm (Fig. 5) and the effect was stronger genotype Kulfo than Hawassa-83. Genotype Kulfo, has shown similar performances in all irrigation frequencies.

Similar observation also reported by Masango [39] where storage root dry mass with lower irrigation frequencies was lower compared to with higher irrigation frequencies. The result is in agreement with the findings of Tshisola [40] who indicated lower tuber dry weight at the low irrigation frequency compared to the high irrigation frequency in Irish potato.

3.4.3 Biomass yield, tuber yield and harvest index

Total dry biomass was significantly (P ≤ 0.001) affected by the main effects of genotype and irrigation frequency. From daily irrigation the highest total dry biomass was obtained from genotype treated with daily irrigation and the least was from genotype treated with seven days interval. Total dry biomass for daily irrigation found to be increased by 45.56 gm per plant and 17.26 gm per plant compared with seven days interval and four days interval respectively (Table 9). Moreover, the main effect of genotype was also significant on total dry biomass and hence, significantly greater production of total dry biomass was obtained from genotype Hawassa-83 (Table 9).

In this study, both genotypes produced maximum total dry biomass under daily irrigation. With respect to genotype difference for total plant dry biomass genotype Hawassa-83 had produced significantly superior total dry biomass. As Tshisola [40] indicated , in line with this finding, reported higher biomass accumulation at the high irrigation frequency.

3.4.4 Tuber yield

In this study, tuber yield was significantly influenced by main effects of genotype and irrigation frequency. Although remarkably higher tuber yield was recorded from genotype irrigated daily and every four days intervals, the difference was not statistically significant at (P>0.05). Genotype irrigated every seven days gave the lowest tuber yield and significantly different from

Table 9. Main effects of genotype and irrigation frequency on Total Dry Biomass (TDBM), Tuber Yield (TY) and Harvest Index (HI)

Treatments	TDBM (g plant^{-1})	TY (g plant^{-1})	HI (%)
Genotype			
Hawassa-83	100.27^{a}	216.27^{a*}	56.86^{a}
Kulfo	66.78^{b}	172.01^{b}	40.64^{b}
Tukey's HSD$_{(0.05)}$	9.2172	31.758	6.4956
Irrigation frequency			
Daily watering (control)	104.47^{a}	261.79^{a}	53.59^{a}
Four days interval	87.21^{b}	228.24^{a}	53.51^{a}
Seven days interval	58.91^{c}	92.39^{b}	39.15^{b}
Tukey's HSD$_{(0.05)}$	13.822	47.623	9.7407
F-test values			
Genotype (G)	62.66***	9.22*	29.61***
Irrigation frequency(I)	39.42***	50.50***	10.36**
G x I	3.46^{ns}	1.12^{ns}	1.98^{ns}
SEM ±	7.33	25.25	5.16
CV (%)	10.74	15.93	12.97

**Means in the same column followed by the same letter are not significantly different at the 5% probability level*

daily irrigation. Daily irrigation produced more than two fold tuber yield over seven days interval (Table 9). Furthermore, genotype Hawassa-83 produced significantly more (216.27 gm per plant) tuber yield over Kulfo (172.01 gm per plant) (Table 9).

This finding was consistent with the finding of [23] who reported that high tuber yield at higher irrigation interval because the rate of tuber yield increased with progressive increase in irrigation frequency, this perhaps due to improved root system which enables the plant to utilize more moisture from the soil. This finding aligned correctly with previous findings of several other investigations [39,40].

3.4.5 Harvest index

ANOVA analysis result indicated that, maximum harvest index was observed from daily irrigation whereas minimum was recorded from seven days interval. In comparison to daily irrigation, seven days interval deviates significantly from daily irrigation whereas four days interval was found to be insignificant. As to the magnitude of reduction, seven days interval irrigation frequency treatment was diminished by 4.44 gmgm^{-1} compared to the daily irrigation (Table 9). In addition to this, there was also genotype difference for harvest index, genotype Hawassa-83 had significantly higher (56.86 gmgm^{-1}) harvest index than genotype Kulfo (40.64 gmgm^{-1}) (Table 9).

Under non-limiting condition (control), both genotypes found to have significantly higher harvest index. Furthermore, in this study genotype Hawassa-83 had higher harvest index than genotype Kulfo. As Bhagsari and Ashley [41] noted that frequently irrigated treatment produced relatively higher HI values on sweet potato, demonstrating that more assimilates were translocated efficiently to the main sink, compared to the other plant parts. The study of [39] also agreed with the current result, sweet potato crop under higher irrigation frequency had better harvest index, thus enabling photosynthesis efficiently translocate to the main sink (storage root).

4. CONCLUSION

Morphological parameters of sweet potato genotypes were significantly influenced depending on irrigation interval, genotypes and their interaction. Extension of irrigation interval to seven days significantly reduced leaf area, leaf number, vine length, branch number and internode length of the sweet potato genotypes. Growth reduction was stronger with Hawassa-83 and when irrigation frequency with holds for longer period of time (seven days) than daily or every four day irrigation intervals. Physiological parameters such as Stomata density, specific leaf area and leaf area ratio were remained constant under different irrigation intervals. Similarly, photosynthetic rate, transpiration rate and stomata conductance were reduced as irrigation intervals extended to seven day intervals. Extension of an irrigation interval to seven days strongly reduced instantaneous water use efficiency in Hawassa-83 but increased in Kulfo genotype suggesting that Kulfo had better water utilization efficiency than Hawassa-83.

Finally, although yield and yield component did not respond to the interaction effect between irrigation interval and genotype, extension of irrigation interval to seven days significantly reduced tuber dry matter, total tuber yield and harvest index and the effect was stronger in Kulfo than Hawassa-83 genotype. The investigation suggested that, genotype HHawassa-83 is less adaptive to moisture stressed agro ecology than Kulfo genotype.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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