MORPHO - PHYSIOLOGICAL BASED SCREENING OF SWEETPOTATO (*Ipomoea batatas L.*) VARIETIES FOR MOISTURE STRESS CONDITION AT HAWASSA, ETHIOPIA

MSc. THESIS

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HAWASSA UNIVERSITY, HAWASSA, ETHIOPIA

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ADVISORS'APPROVAL SHEET

(Submission Sheet – 1)

This is to certify that the thesis entitled "**Morpho-physiological based screening of sweetpotato (*Ipomoea batatas* L.) varieties for moisture stress condition at Hawassa, Ethiopia**" submitted in partial fulfillment of the requirements for the degree of **Masters of Sciences** in plant and horticultural science (Specialization: **Horticulture)** is a record of original research carried out by **Serkalem Eshetu**, under our supervision, and no part of the thesis has been submitted for any other degree or diploma. The assistance and help received during the course of this investigation have been duly acknowledged. Therefore we recommend that it be accepted as fulfilling the thesis requirements.

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As members of the Examining Board of the Final MSc Open Defense, we certify that we have read and evaluated the thesis prepared by **Serkalem Eshetu** entitled "Morpho-physiological based screening of sweetpotato (*Ipomoea batatas* L.) varieties for moisture stress condition at Hawassa Ethiopia" and recommend that it be accepted as fulfilling the thesis requirement for the degree of the Master of Science in Horticulture

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STATEMENT OF THE AUTHOR

I declare that this thesis is my real work and all sources of materials used for this thesis have been properly acknowledged. I seriously declare that this thesis is not submitted to any other institution anywhere for the award of any academic degree, diploma or certificate.

Name: ___________________________________ **Signature:** __________________

Place: College of Agriculture, Hawassa University, Hawassa

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DEDICATION

I dedicate this thesis manuscript to my beloved mother Muna Taddese for her support throughout my life and lost her before the end of this paper.

LIST OF ABBREVIATIONS AND ACRONYMS

A	Photosynthesis
ABA	Abscisic Acid
BSc	Bachelor of Science
CEC	Cation Exchange Capacity
ANOVA	Analysis of Variance
ARC	Agricultural Research Center
CO_2	Carbon Dioxide
CSA	Central Statistical Agency
DAP	Diammonium Phosphate
DGC	Department of Graduate Council
E	Transpiration Rate
EC	Exchange Capacity
ETc	Crop evapotranspiration
FAO	Food and Agriculture Organization
FC	Field Capacity
Fv/Fm	Maximum Quantum Yield
g_s	stomatal conductance
IRT	Infrared Thermometer
MSc	Masters of Science
PAR	Photosynthetic active radiation
pH	Potential hydrogen
PPM	Parts per million
PSI	Photo System One
PSII	Photo System Two
PWP	Permanent Wilting Point
RLWC	Relative Leaf Water Content
SAS	Stastical Analysis Software
UPVRC	Uganda Plant Variety Release Committee
UV	Ultra Violet

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Morpho - Physiological Based Screening of Sweetpotato (*Ipomoea Batatas L.*) Varieties for Moisture Stress Growth Condition at Hawassa, Ethiopia

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ABSTRACT

Sweetpotato is one of the potential root and tuber crop playing major role in food security due to its high yielding and adaptability to diverse environmental conditions. However, various constraints like biotic and abiotic factors reported for the low productivity of the crop. Therefore, the study was designed to evaluate sweetpotato varieties morpho-physiological characters under different irrigation interval in shade house condition at Hawassa, Ethiopia from October to March, 2019/20. The treatment were comprised of a factorial combination of three sweetpotato varieties (NASPOT 12 O, Kulfo and Dilla) and four irrigation intervals (daily, 7 days, 14 days and 21 days) in complete randomized design (CRD) with three replications. Data on morpho-physiological and yield parameters were collected. The result revealed that, main effect of varieties and irrigation interval has a significant effect on vine length, leaf temperature and vine fresh weights. Leaf number, leaf area, chlorophyll a, b and total (TC), maximum quantum yield, proline content, photosynthesis rate, transpiration rate, stomata conductance, IWUE, RLWC, tuber fresh weight, total biomass and tuber number were significantly influenced due to interaction effect of two main factors. Most of parameters were significantly reduced with increased irrigation interval except Proline content and leaf temperature. Maximum tuber fresh weight (700 g) was recorded from NASPOT 12 O as compared to Dilla (533.33 g) and Kulfo (233.33 g) varieties. In the case of physiological response NASPOT 12 O treated with daily irrigation gave maximum concentration of chlorophyll a, b and total (TC), Photosynthesis rate, transpiration rate and stomata conductance in leaf as compared to other varieties. The maximum proline content was observed from variety "NASPOT 12 O" with 21 days irrigation interval whereas; the minimum was from all varieties with daily, seven and fourteen days irrigation which was statistically similar. Dilla and NASPOT 12 O varieties had better relative leaf water content as irrigation interval increases but variety Kulfo show strong reduction. It can be concluded that, Variety "NASPOT 12 O" was considered to be more tolerant as compared to other varieties. This is, therefore, NASPOT 12 O with 7 days irrigation interval recommended and in areas where moisture is a limiting factor NASPOT 12 O varieties with 14 days irrigation interval might be recommended for small scale farmers. Consequently, further research is needed for morphological and physiological responses under different varieties and water stress under open field condition before a generalized conclusion can be drawn.

Key words: Varieties, irrigation interval, sweetpotato, morphological and physiological response

1. INTRODUCTION

Background

Sweetpotato (*Ipomoea batatas* L.) is herbaceous dicotyledonous plant with creeping, perennial vines and adventitious roots which belongs to Convolvulaceae family (Oggema *et al*., 2007). It is highly heterozygous cross pollinated tuberous root crop in which many of the traits show continuous variation (Markos and Loha, 2016). Sweetpotato was originated from Latin America (Gichuki *et al.*, 2003). It is grown throughout the world in diverse environments, often by small holder farmers in marginal soils, using low inputs and little attention (Amare *et al*., 2014).

Sweetpotato is major source of energy due to its high carbohydrate content which ranges between 80 to 90% by its dry weight. These carbohydrates consist mainly of starch, sugars and a low quantity of pectin, hemicelluloses, and cellulose, high in calcium, potassium, vitamin A and C, rich in dietary fiber, has small amount of iron, has more than 15 health benefit, source of income for farmer, row material for industries and also used as feeds for animals (Woolfe, 1992; Lebot, 2009).

Sweetpotato is the 3rd most important root and tuber crop next to potato and cassava. About 105.19 million tons of sweetpotato roots are produced from an area of 8.62 million ha with productivity of 12.20 ton/ ha (FAO, 2016). China, Nigeria and Tanzania are the leading producing countries in the world with the production of 70,963,630; 3,478,270 and 3,345,170 metric tons respectively (Rolando, 2017).

In Ethiopia sweetpotato is majorly cultivated in southern, southwestern and eastern parts of the country and recognized as the 3rd important root and tuber crop next to enset and potato. Over 1.85 million tons of sweetpotato storage roots are produced during the main growing season from an area of over 53,499 ha with the productivity of 33.4 ton/ha (CSA, 2018). Gurmu and Mekonen (2017) reported that about 18 white and six orange fleshed sweetpotato varieties were released in Ethiopia. However, most of these varieties are obsolete and not under production. Awassa-83, Kulfo and Tula are the most widely used sweetpotato varieties by the farmers in the study area due to their relatively better root yield in areas where sweetpotato virus diseases pressure is low.

Production and productivity of sweetpotato in Ethiopia is very limited by biotic and abiotic factors out of which moisture stress is one of the major abiotic constraints (Markos and Loha, 2016). Moisture stress is one of the major yield limiting abiotic factors in sweetpotato production that are causing an annual estimated yield loss of 25% (Placide *et al.*, 2013). It is associated with adverse morphological, physiological, biochemical and molecular changes among the sweetpotato varieties (Henderson and Fukai, 1998). Varieties are considered to be under drought stress when they face water limitation in the soil, and when they are subjected to the constant loss of water through evapotranspiration started by atmospheric conditions (Nozipho *et al.*, 2015).

Inherent morphological mechanisms of drought avoidance and phenotypic plasticity are the most important natural defense mechanism for plants to tolerant towards moisture stress conditions (Farooq *et al.*, 2009). Reduced plant size, leaf area, and leaf area index (LAI) are a major mechanism for moderating water use efficiency and reducing injury under drought stress condition (Mitchell *et al.*, 1998). Plants are able to survive dehydration through osmotic adjustment by production of proline and amino acids that stabilize proteins (Zhang *et al.*, 2009; Abobatta, 2019).

Yooyongwech *et al*. (2017) reported reduction of photosynthesis, stomatal conductance, transpiration and maximum quantum yield of photosystem II under drought condition. Similarly, Saraswati (2007) reported redaction of photosynthesis, transpiration, leaf water potential and relative leaf water content of sweetpotato varieties under lower soil water content than well watering.

Moisture stress induces a range of physiological and biochemical responses in plants such as stomatal closure, repressions of growth and activation of respiration (Flexas *et al*., 2004; Roelfsema and Hedrich, 2005; Rennenberg *et al*., 2006). Moisture stress affects the photosynthesis ability of plants by changing the content and components of chlorophyll, reducing the net CO_2 uptake by leaves and by decreasing activities of enzymes in the Calvin cycle (Lawlor and Tezara, 2009).

Soil moisture stress is a crucial factor that limits the production of storage root and marketable yield of sweetpotato varieties by affecting early growth. Ekanayake and Collins (2004) classified sweetpotato crops in to different varieties with regard to their ability to adapt drought conditions after subjecting the crop in to normally irrigated and water stressed conditions.

Lewthwaite and Triggs (2012) observed significant differences in most of the sweetpotato varieties with the higher irrigated levels and produced higher yield. Furthermore, a severe reduction in sweetpotato root yield and a parallel decline in biomass at severe water reduction were reported by Heerden and Laurie (2008). Saraswati *et al*. (2004) conducted a pot experiments on sweetpotato variety screening and they found severe reductions in its biomass, which was associated with a reduction in fresh and dry root biomass of the drought stressed treatment. The resistance stage occurs when the photosynthetic capacity of the plant was reduced below the maximum potential level. At this stage, the plants were developing adjustment mechanisms and regulatory metabolic process to cope with the water deficit stress (Anjum *et al*., 2011).

Moisture stress reduces stem extension and internodes diameter of sweetpotato varieties. The severity of this reduction was reported to differ with different varieties (Saraswati *et al*., 2004). Inhibition of cell expansion and cell growth is mainly the result of low turgor pressure under water stress conditions. Osmotic regulation can enable the maintenance of cell turgor for survival or can assist plant growth under severe drought conditions. Water stress reduces leaf growth which in turn reduces the leaf area of sweetpotato crops (Jaleel *et al*., 2009).

Sweetpotato is generally drought tolerant tuberous root crop, but the selection of appropriate varieties for drought conditions remains a priority. Heerden and Laurie (2008) noted 60% estimated yield reduction under drought stress condition. Screening of crop varieties with increased tolerance to drought is therefore an important strategy to meet global food demands with less water. Sweetpotato has a potential of giving 50 to 60 ton/ha in Ethiopia; however, currently obtained from farmer's field is 34.5 ton/ha (CSA, 2018). This huge yield gap between the world and Ethiopian average is attributed to drought stress and other factors (Heerden and Laurie, 2008). Despite the importance of sweetpotato roots to household food security in Ethiopia, the information on its morphological and physiological response on water stress conditions among the farmers commonly produced varieties are very limited. However, low understanding regarding water stress and its adjustment and adaptation capacity of the crop to changing and more adverse climate conditions are the main problems in improving production and productivity of the crop. In addition, farmers have limited awareness to the effect of moisture stress and still there is a gap on the mechanisms of conferring drought tolerance in sweetpotato production despite its negative effect on the performance of the crop. Therefore, this study was undertaken to screen the sweetpotato varieties based on its morpho-physiological performances under different irrigation interval.

1.1. General objective

- To evaluate the effect of irrigation interval on the growth, physiology and yield performance of different sweetpotato varieties.

1.2. Specific objective

- To study morphological response of sweetpotato varieties to different moisture stress
- To study physiological response of sweetpotato varieties to different moisture stress.
- To identify the sweetpotato varieties to different levels of moisture stress condition.

2. LITERATURE REVIEW

2.1. Botanical description of sweetpotato

Sweetpotato is a highly heterozygous cross pollinated crop in which many of the triats show continuous variation (Markos and Loha, 2016). It belongs to kingdom plantae, order solanales, family covonvolaceae, genus ipomoea and species I. batatas with large chromosome number (2n=6X=90) (Ozias and Jarret, 2013). Sweetpotato stems are usually long and trailing and bear lobed or unlobed leaves that vary in shape (Sani *et al*., 2014).

The flowers, borne in clusters in the axils of the leaves, are funnel-shaped and tinged with pink or rose-violet. The edible part is the much-enlarged tuberous root, varying in shape from fusiform to oblong or pointed oval (Britannica, 2021).

Root colors range from white to orange and occasionally purple inside and from light buff to brown or rose and purplish red outside. Although variation in storage root skin color and flesh color is abundant, two major types exist which define usage (Rolando, 2017). The staple type with white flesh and white or purple skin has a high starch and dry- matter content. The dessert types with orange flesh and orange skin with a high sugar and beta-carotene content (AFA, 2011).

2.2. Sweetpotato production Status

Sweetpotato is a tropical perennial crop cultivated as an annual in temperate climates; grown in more than 100 countries in tropical, sub-tropical and temperate climates. It is used as a major food staple in a few countries, as an alternative staple in many countries, and as an incidental or luxury addition to the diet in many countries (Collins, 1998). It is one of only seven world food crops with an annual production of more than 100 million metric tons per year ranking thirteenth globally in production value among agricultural commodities. It is cultivated primarily for the enlarged edible storage roots which provide high amounts of starch to staple diets (Anoma and Thamilini, 2016). Asia accounts over 80% of the world sweetpotato production and China is the leading producing country in the world; whereas Africa covers about 15% and the other 5% is covered by the rest of the world.

In Ethiopia, sweetpotato is grown by smallholder farmers as one of the food security crops. It is an integral part of the cropping system in the eastern, southern and south western parts of the country. Use as an export crop is rare and production is usually to meet local or national needs (Gurmu and Mekonen, 2017).

2.3. Ecological Requirement of Sweetpotato

Sweetpotato is a tropical and sub-tropical plant that requires warm nights and sufficient sunshine. It can adapt to more temperature climates providing the average temperature does not drop below 20 °c and minimum temperature stay above 15 °c and when temperature falls below 10 °c, growth is severely retarded. In other words it can be cultivated between the 40°N and 32°S latitudes in the hemispheres. The optimum altitude range is 1500-1800 masl. It performs poorly and the maturity period is also extended when planted in areas with more than 2000 meters elevation (Gurmu and Tesfaye, 2016). But it can grow at altitudes from sea level to 3000 meters above sea level (masl) along the equator (Huaman, 1987). Soil requirements are best meet in conditions with a pH of 4.5 to 7.0 in light- to medium-textured, sandy loam and well-drained soils (Birhanu *et al*., 2016). Sweetpotato responds well to increasing moisture but is considered a drought-tolerant crop because it is deep rooted and capable of developing storage roots under very dry conditions. Excessive moisture inhibits storage root development in early growth stages and causes decay of storage roots in later growth stages (Collins, 1998).

The prolific root system of sweetpotato makes it a drought tolerant crop, although supplementary irrigation is required at the time of planting for proper sprouting and establishment (Mukhopadhyay *et al*., 2011).

2.4. Sweetpotato Production Constraints in Ethiopia

Sweetpotato productivity is limited by both abiotic and biotic constraints, leading to poor yields at farm level (Muluneh *et al*., 2019). These include low soil fertility, drought, shortage of improved varieties, shortage of planting materials, pests and diseases particularly viruses, post-harvest problems such as storage and market availability and demand as well as low socioeconomic status in some communities (Gurmu *et al*., 2015).

2.5. Morphological response of sweetpotato to drought stress

Sweetpotato is drought tolerant crop however different varieties have different yield responses. According to Yooyongwech *et al*. (2017), storage root of sweetpotato decreases with increasing drought. Root yield is particularly vulnerable to water restriction during the time of plant establishment, as any lignifications of developing roots may impair their potential for the lateral thickening associated with carbohydrate storage (Lewthwaite and Triggs, 2012). The same response had observed by Saqib *et al*. (2017) who reported under water stress conditions vegetative growth and storage root yield of sweetpotato variety decreased. Studies by Jaleel *et al*. (2004) reported that water stress can reduce yield in many crop plants and that different crops respond differently to water stress.

Lewthwaite and Triggs (2012) observed significant differences in most of the varieties evaluated, with the higher irrigated ones producing a higher yield, although some sweetpotato varieties did not show any difference in yield at different irrigation levels. Furthermore, a severe reduction in sweetpotato root yield and a parallel decline in biomass at severe water reduction were reported by Heerden and Laurie (2008). As the canopy represents the only source of biomass for subsequent partitioning to the storage root in sweetpotato, if biomass is limited, it would consequently impose a source limitation of assimilate to storage roots thus lowering final yield (Jaleel *et al*., 2009). Roots are the first signal perception organ in plant's response to water limitation in the soil (Kim et al., 2009).

Saqib and his colleagues (2017) studies on sweetpotato (white star) cultivar using three irrigation intervals (7, 14 and 21 days for summer crop, and 14, 28 and 42 days for winter crop) with two planting systems (bed planting and ridge planting) found that vine length, number of branches and average leaf area significantly reduced as the irrigation interval increased. Drought tolerance is associated with the lowest percentage of growth reduction, less water consumption, higher leaf water potential, and delayed wilting under imposed drought stress conditions.

It is known that leaf area in sweetpotato plants decreases as water stress increases (Nedunchezhiyan *et al*., 2012). Lewthwaite and Triggs (2012) reported that, sweetpotato cultivars planted in the field showed a large reduction in canopy cover under water deficit which also experienced very large reductions in its yield. Heerden and Laurie (2008) also noticed large reductions in yield for variety Resisto which could be directly linked to low LAI under water deficit conditions.

Applying Irrigation depths of 50, 75, 100, and 125% of crop evapotranspiration (ETc) Fabio *et al.* (2018), reported the LAI of Amanda and Duda varieties increased with irrigation depth, with higher values at 100% of the ETc Significant effects were detected in LAI of different varieties in reaction to moisture stress and all the varieties showed the effect of poor soil water, especially between the control and mild moisture stress treatments. Lewthwaite and Triggs (2012) also reported a decline in canopy cover of certain sweetpotato varieties planted under both drought and wet conditions. At 60 DAP(days after planting), variety Isondlo and W-119 were the only cultivars to experience a significant decrease in canopy cover between the control and mild moisture stress treatments, namely, a 91% and an 85% reduction, respectively. At 60 DAP (days after planting), no significant decline in LAI values was noticed between the mild and severe moisture stress treatments (Robert, 2015).

2.6. Physiological response of sweetpotato to drought stress

Physiology is fundamental process such as photosynthesis, transpiration, stomatal conductance and etc. Sweetpotato exposed to drought stress recorded low photosynthesis by reducing chlorophyll fluorescence, stomatal conductance, intercellular carbon dioxide (CO_2) concentration and CO_2 assimilation rate primarily through stomatal closure (Heerden and Laurie**,** 2008).

Chlorophyll Concentration

Photosynthetic pigments are important to plants mainly for harvesting light and production of reducing power (Jaleel, 2008). Both the chlorophyll a and b are prone to soil dehydration (Farooq *et al*., 2009). Foliar photosynthetic rate of higher plants is known to decrease as relative water content and leaf water potential decrease. Severe levels of drought are capable of causing irreversible damage to photosynthetic apparatus. Both stomatal and non-stomatal limitations were generally accepted to be the main determinants of reduced photosynthesis under drought stress conditions. Yooyongwech *et al*. (2014) also reported a reduction of both chlorophylls a and b and total chlorophyll at high water stress in sweetpotato crop. This reduction was reported to be associated with an increase in electrolyte leakage caused by leaf senescence and reduced water use in plants (Nozipho et al., 2015).

Babita *et al*. (2010) observed 4-6 fold increase in proline accumulation in castor plant grown under 10-15% water deficit conditions compared to the control plants. Yooyongwech *et al*. (2014) also reported free proline content in the leaf tissues of sweetpotato varieties was increased depending on the degree of soil water content, reduction under well watering and 40% SWC and It rapidly increased to high concentration in the water deficit stressed plants(25% and 8% SWC).

Stomata related traits (Number, Length and Width) aperture

Stomata traits such as number, length and width are considered to be key determinants of growth rate and water balance in plants (Dillen *et al*., 2008). Stomata traits are strongly controlled by genetic factors (Gailing *et al*., 2008). This phenomenon preserves a level of plasticity in response to different water stress conditions. At higher water stress level (water deficit), plants have smaller stomata with less length and width and with a more stomata density to control transpiration and save water (Bosabalidis and Kofidis, 2002; Hetherington and Woodward, 2003; Belhadj *et al*., 2011). On the other hand, as water stress level increased, decreased stomata number has been reported (Xu *et al*. 2003). In sweetpotato, the function of stomatal closure, to limit water loss and reduce CO_2 assimilation, under water deficit stress has been well investigated, especially in the sensitive varieties (Haimeirong and Kubota, 2003).

Leaf Gas Exchange parameters

The gas exchange of the plants (photosynthetic rate, transpiration rate and stomatal conductance) is the principal plant process responsible for plant biomass production and for plant adaptation to adverse environment (Lawlor and Tezara, 2009). Stomatal opening, which controls gas exchange, is a sensitive indicator for water stress. Stomatal conductance concerns the relationship between carbon assimilation and water loss by transpiration (Ludlow, 1980).

Yooyongwech *et al*., (2014) studies three sweetpotato (PROC 65-3, Japanese yellow and Tainnung 57) genotypes under well watering and four water deficit stress conditions (40%, 29%, 15% and 8% soil water content(SWC)) in pot culture and reported significant reduction of photosynthesis rate, transpiration rate and stomatal conductance where soil water content decreases from well watering to 8% SWC. Stress-inducing environmental changes not only damage the photosynthetic process, but also affect stomatal movement, light absorption and the biochemical pathways for CO_2 fixation (Cornic, 2000). Although the response of stomata to environmental and physiological factors is complex, it is known that stomatal conductance varies with leaf irradiance, leaf temperature, atmospheric water vapour pressure deficit and CO_2 concentration. Heerden and Laurie (2008) indicated that a decline in conductance is transient in less severe drought conditions in sweetpotato plants. Plants under drought conditions have a lower photosynthesis rate (Yooyongwech *et al*., 2013), reducing energy and metabolite availability for growth and optimal crop production (Kulkarni and Phalke, 2009).

Leaf Water Related Parameter's

Leaf temperature of plants under water stress is higher than those with adequate water availability. This parameter is used to assess indirectly the effects of water availability, as the optimal stomata conductance is observed with a leaf temperature between 25 and 30 °C (Machado *et al*., 2005, Testi *et al*., 2008).

Plants can be evaluated for their leaf water potential correlated to gas exchange, growth, and physiological parameters (Williams and Araujo, 2002). The leaf water potential increased exponentially with increasing water availability in the soil. On the other hand, the linear increase in the leaf water potential was observed for the potato culture (Gajanayake *et al*., 2014). The reduction of water potential may induce osmotic adjustments in plants to promote leaf hydration and the production. According to Fabio (2018), the decrease in leaf temperature of sweetpotato varieties was more evident with increasing soil moisture, equivalent to an irrigation depth of 275 and 310 mm for the Amanda and Duda, respectively. Therefore, increasing and decreasing leaf temperature was proportional to water irrigation applied. Effective transpiration control and faster water movement in plants at high temperatures involves a cooling system, which protects metabolic processes.

Plants respond to a changing climate with a change in temperature, precipitation, and CO_2 increases WUE until the leaf is exposed to temperatures exceeded the optimum for growth and then WUE begins to decline. Leaves subjected to water deficit (drought stress) show varying responses in WUE. The response of WUE at the leaf level is directly related to physiological process controlling the gradients of CO_2 and H_2O for eg. Leaf: air vapor pressure deficits, between the leaf and air surrounding the leaf (Jerry, 2019). WUE of sweetpotato cultivars increased until the 75% water depth of the ETc. The increase of the WUE with the greater accumulation of dry biomass is due to greater CO_2 diffusion by stomata. The reduction in the growth of these plants is due to water stress limiting stomatal conductance, transpiration, leaf growth (LAI) and chlorophyll concentration, proportional to soil moisture conditions. The functional relationship between soil moisture and growth is essential to optimize irrigation management at different growth stages (Fabio *et al*., 2018).

Saraswati (2007), reported application of a severe water stress by reducing the water availability to 30% of soil field capacity, decreased the water use efficiency of Lole and Wanmun sweetpotato cultivars.

2.7. Drought Adaptation Mechanisms in Plants

Drought stress is the most prevalent environmental factor limiting crop productivity (Basu *et al*., 2016). Plants use different mechanisms to cope with drought stress such as; drought resistance (avoidance and tolerance) and drought escape.

Drought Avoidance

Drought avoidance is the ability of plants to maintain relatively high tissue water potential despite a shortage of soil moisture. Drought avoidance can be achieved by enhanced water uptake associated with adaptive aspects such as increased root depth for water uptake, altered rooting patterns (Jackson *et al*., 2000) by reduced water loss as a result of mechanisms involving stomatal closure, by leaf rolling or folding, reduced evaporative leaf surface area, adjustments to the leaf energy balance through reductions in light absorption or modifications to heat and mass transfer in the leaf boundary layer (Bray, 1997; Mitra, 2001; Blum, 2005; Jones, 2014).

In sweetpotato, the function of stomatal closure to limit water loss and reduce CO_2 assimilation under water deficit stress has been well investigated especially in the sensitive varieties (Haimeirong and Kubota, 2003). During soil dehydration, the water potential in the soil is generally decreased to limit the water absorption and translocation from sink to source, and signals stomatal closure by the function of guard cell, represented by stomatal conductance (Heerden and Laurie, 2008; Suravoot *et al*., 2014).

Drought Tolerance

Drought tolerance is defined as the relative capacity to sustain or conserve plant function in a dehydrated state. This is sometimes seen as the second defense line after dehydration avoidance (Abobatta, 2019). Moreover, drought tolerance is the ability of plants to withstand water-deficit with low tissue water potential (Chaves *et al*., 2003). Some of drought tolerant mechanisms are maintain turgor through osmotic adjustment, decreased cell volume, amplify cell membrane, resistance to desiccation and increase cell elasticity.

Drought-tolerant plants are able to survive dehydration through osmotic adjustment and production of molecules that stabilize proteins (Abobatta, 2019). Proline and amino acid are involved in osmotic adjustment (OA) and protection of cells during dehydration (Zhang *et al*., 2009). However, plants may use more than one mechanism at a time to cope with drought (Agbicodo *et al*., 2009). Moreover, several studies indicate that plant root systems play an important role in plant adaptation to a drought stress habitat. In situations where drought stresses increases the concentration of proline increases. Free proline accumulation at the cellular level play a key role in osmotic adjustment, which promotes drought defense mechanisms (Ghodsi *et al*, 1998; Yooyongwech *et al*., 2016).

Drought Escape

Drought escape is adaptive mechanism which involves rapid plant development to enable the completion of the full life-cycle before drought event coming (Shavrukov *et al*., 2017). This mechanism involves early flowering, early maturity, variation in the duration of growth depending on the extent of water deficit and remobilization of photo assimilates (Shavrukov *et al*., 2017). Plants effectively escape drought when their Phenological development (early flowering and maturity) matches with periods of soil moisture availability and where the growing season is shorter and terminal drought stress predominates (Charles, 2014).

3. MATERIALS AND METHODS

3.1. Description of Study Area

Pot experiment was conducted under shade house condition during the main cropping season (October to March, 2019/20) at Hawassa University College of Agriculture Research Field, which is located 273 km from Addis Ababa. It is found at an altitude of 1750 masl and 7^{o} 3' N latitude with 38^{o} 28' E longitude. The mean annual rainfall is about 971.9 mm, average temperature 20.85 (National Meteorology Agency, 2019).

The shade house used for this experiment was fenced with metal wire to defend the entrance of any undesirable body in to the shade house. The top of the shade house was covered by transparent corrugated tin.

3.2. Experimental Materials

Three sweetpotato varieties (NASPOT 12 O, Kulfo and Dilla) were used in this experiment and the planting materials were collected from South Agricultural Research Institute Hawassa. The varieties are well performing in terms of nutritional value, high yielding orange flesh color and under wide range of agro-ecological conditions and the description are indicated in Table 1.

Table 1. Description of sweetpotato varieties used for this study

Variety	**Maturity (days)**	**Flesh color**	**Yield tone/ha**	**Dry matter content (%)**	**Years of release**	**Origin**
NASPOT12 O	120	Intermediate Orange	26.5	31.7	2013	Uganda
Kulfo	90-120	Intermediate Orange	13.7	22.9	2005	Ethiopia
Dilla	120-150	Deep Orange	26.8	31.4	2019	Ethiopia

Source, (Mwanga *et al*., 2016; Gurmu and Mekonen, 2019)

3.3. Treatments and Experimental Design

A factorial combination of three sweetpotato varieties (NASPOTS 12 O, Kulfo and Dilla) and four irrigation intervals considered as moisture stress (Daily, Seven days, Fourteen days and Twenty-one days) were used in Complete Randomized Design (CRD)**.** The experiment has 12 treatments with three replications. A total of 36 pot and 5 plants per pot with a total of 180 plants were used. Each treatment combination was assigned randomly to the experimental units within a replication. A uniform pot size of 58 cm diameter and 18 cm depth was used for each unit.

Table 2. Experimental treatment combination

	Watering interval			
	Daily(Control)	Seven days interval	Fourteen days interval	Twenty-one days interval
Varieties	NASPOT 12	NASPOT 12 O	NASPOT 12 O	NASPOT 12 O
	Kulfo	Kulfo	Kulfo	Kulfo
	Dilla((Ukr/Eju-13)	Dilla	Dilla	Dilla

3.4. Experimental Procedure and Crop Management

Sweetpotato is commercially propagated by its vine so quality of vines free from insect and diseases was selected directly on the field from South Agricultural Research Institute, Hawassa.

A 20 kg of sieved (2 mm sieve) composite soil were filled in the plastic pot with perforated at the bottom to allow air and water movement and water was applied before planting. Nitrogen fertilization was added with the amount of 200 kg ha^{-1} (Ribeiro *et al*., 1999) at 30 and 60 days after planting. Tip cuttings of the vine 40 cm long with 4 nodes were planted at depth of 15 cm at 29th October of 2019 based on the recommendation of (AARC, 2016). During the experimental period the climate data (minimum and maximum temperature, relative humidity) were recorded.

The amount of water required to bring the soils in the pots to field capacity were calculated using gravimetric method of Topp (1993). It took 5 months to complete the research work till its final harvesting date. Planting was done upright at a depth of 15cm arranged on experimental pots. All cultural practices recommended by AARC (2016) and Saqib (2017) were followed. Since there was an occurrence of have scored disease incidence (Fusarium wilt) during early vegetative stage of the crop, recommended rates of Power 76 WP chemical were applied. The four irrigation intervals (daily, seven days, fourteen days and twenty-one days) watering were carried out keeping the soil at field capacity (FC=32.67%).

3.5. Experimental soil sampling and analysis

Composited samples of soil consisting of top soil, compost and sand were analyzed for its physical (percentage of sand, silt, and clay, and soil textural class) and chemical properties (pH, total nitrogen, organic carbon, available potassium, wilting Point, electro conductivity and moisture content at FC) using standard laboratory procedures at Hawassa University, College of Agriculture.

The soil pH values were determined in soil water suspension 1:2.5 using glass electrode pH meters (Jackson, 1967). Determination of particle size distribution (texture) was carried out hydrometrically (Day, 1965). Based on the oxidation of organic carbon with acid potassium dichromate, Organic matter content was determined using Walkely‘s and Black methods respectively (Jackson, 1967). Total N was determined as mentioned by Black (1965).

The results of the physical and chemical properties of the soil of the study site were presented in Table 3. The analysis report indicated that, the experimental media were found to the growing media quality of sweetpotato as recommendation by (Tadesse *et al*., 1991; Jones, 2002).

Table 3. Physico-chemical properties of experimental soil

Physical and chemical properties	**Values**
Sand (%)	76
Silt (%)	18
Clay (%)	6
Soil textural class	Loam Sand
pH	7.5
Available potassium (ppm)	13
Organic carbon (%)	4.67
Total nitrogen (%)	0.259
Electro conductivity (µs)	5.04
Moisture content at FC (%)	32.67
Wilting Point (%)	22.1
Bulk density (g/m^2)	1.02

3.6. Data Collection and Measurement

3.6.1. Meteorological data

Air temperature, relative humidity and vapour pressure deficit

The maximum and minimum temperature and relative humidity during the experimental period from October to March, 2019 were measured on randomly selected 20 days using mini data loggers (Testo 174, Version 5.0.2564.18771, and Lenzkirch, Germany). To avoid direct sunlight and moisture the data logger was covered from the top with flat carton and hanged closer to the plant canopy. The vapour pressure deficit of the shade house was calculated based on the temperature and relative humidity recorded using VPD-Auto grow software (https://cals.arizona.edu/ceac). The climate data were recorded every hour for 20 days and the average value of 20 days measurements is represented.

3.6.2. Morphological data

Branch number (count): - Branch number per plant was counted from 3 randomly selected plants in each treatment at vegetative growth stage (60 days).

Root number (count): - Number of adventitious root per plant was counted from 3 randomly selected plants in each treatment at vegetative growth stage.

Leaf number (count/plant): - The number of leaves per plant was counted from randomly selected plants in each treatment at vegetative growth stage.

Leaf area per plant (cm^2): - Leaf area was determined using a portable area meter model Ll-3000A belt driven leaf area meter (LiCor Lincoln, Nebraska, USA) at 60 days after the start of the treatments, expressed in cm^2/plant.

Vine length (cm): - refers to the length of vines from the base to the apex of the plant. It was measured using a measuring tape at 60 days after treatment applied by randomly selecting three plants from each treatment.

Internode length (cm): - Average expression of four internodes of the vines. 3 plants from each treatment were measured when tuberization starts (60 days after treatment).

3.6.3. Physiological data

Determination of chlorophyll concentration

Chlorophyll a (chla), Chlorophyll b (chlb) and Total Chlorophyll (TC) contents in the leaf tissues was assessed according to the method of Shabala *et al*. (1998)**.** Leaf material was collected from the second and third nodes by counting down from shoot to tip. For sampling of leaf three plants from each treatment was used. For the extraction about 0.2g fresh leaf sample were placed in 15 mL glass vial with 10 mL of 95% alcohol. The glass vials were sealed with Parafilm to prevent evaporation and chlorophyll degradation by light. The homogenized sample mixture was centrifuge for 10,000 rpm for 15min at 40 ℃. The supernatant was separated and 0.5 mL of each concentration level was analyzed in laboratory dark room for Chlorophyll a, and Chlorophyll b at an absorbance of 649 nm and 664 nm wavelength region using a UV-2450 spectrophotometer (Hitachi, Tokyo, Japan).

The following equations were used for the quantification of Chlorophyll a, Chlorophyll b and total chlorophyll (Lichtenthaler and Buschmann, 2001).

$$\text{Chla } (\mu g/ml) = 13.36\ (A664) - 5.19\ (A649)$$

$$\text{Chlb } (\mu g/ml) = 27.43\ (A649) - 8.12\ (A664)$$

TC (µg/ml) = chl a + chl b

Where; A = Absorbance, Chla = Chlorophyll a, Chlb = Chlorophyll b, TC = Total Chlorophyll

Chlorophyll Fluorescence

Chlorophyll fluorescence emission data was collected from adaxial surface of three youngest fully expanded plants in each treatment. Measurement was done using a Handy-*PEA* fluorimeter (Hansatech, Kings Lynn, UK) following the methodology of (Strasser *et al.*, 2004). Before measurement, leaves were dark-adapted in the leaf clip for 30 min. Light was then provided by an array of three high- intensity light- emitting diodes and adjusted to 1500 µmol m^{-2} s^{-1} to ensure that the photosynthesis was saturated during the measurements.

Determination of Proline concentration

Free proline in the leaf tissues was assayed according to the method of Bates *et al.* (1973) at 60 days of vegetative growth stage after treatment applied. First, 50 mg fresh leaf samples were placed in 1mL of ethanol and allowed to overnight at 4 ℃ then the samples were centrifuged at 14000 g for 5 minutes. 100 µL of reaction mix (1:60:20%) ninhydrin, Glacial acetic acid and ethanol was pipetted to each sample. The sample was heated at 95 ℃ for 20 minutes. After cooling at room temperature the supernatant was centrifuged down quickly (1min. 2500 rpm). Then 100 µL of the supernatant was transferred to (96 well plate) and a micro plate reader was used to quantify the value at 520 nm absorbance using Multisken FC.

Stomata number

Stomata number were counted and measured at vegetative state (60 days after treatment) following the procedure of Torre *et al*. (2003). Abaxial side of the leaf surface were covered by thin layer of clear nail polish and waited for 10 min until the nail polish dried to capture the epidermal imprint of the leaves, thereafter, a thin layer covering a surface on the leaves were peeled off using a clear tape and attached on the microscope slide. Then, the imprint were mounted on automatic upright Leica microscope DM5000 with 40x magnification lens fixed with digital Leica DFC425/DFC425C image processing camera (Germany) connected with LAS version 4.8 application. Impression was taken from the three youngest, fully expanded leaves for each treatment.

Gas exchange parameters

Photosynthesis (A), Transpiration rate (E) and Stomatal conductance (g_s) determination

It was measured from 3rd young and fully expanded leaf at the vegetative growth stage (60 days after treatment). The data was taken from three randomly selected plants in each treatment using an open system LCA-4 (LCA-4 Software Version 1.04) ADC portable infrared gas analyzer (Analytical Development Company, Hoddeson, England).

Measurement was done between 10:00 AM and 12:00 PM by maintaining the following specifications: Leaf surface area was 6.25 cm^2, ambient carbon dioxide concentration 386 µmol mol-1, leaf chamber mass flow rate was 251 µmol s-1, atmospheric pressure 840 bar and photosynthetic active radiation (PAR) was manually fixed to 600 µmol m-2 s-1.

Water use efficiency was determined as the ratio between net CO_2 assimilation rate (A) and transpiration rate (E) (Bertolde *et al*., 2012).

Instantaneous Water Use Efficiency (A/E)

The term WUE reflects the balance between gains (kg of biomass produced or moles of CO_2 assimilated) and costs (m^3 of water used or mole of water transpired). In this study, instantaneous water use efficiency was determined by the ratio of carbon gain in photosynthesis and loss of water in transpiration. It was calculated based on the data generated by open system LCA-4 (LCA-4 Software Version 1.04) ADC portable infrared gas analyzer (Analytical Development Company, Hoddeson, England,) at vegetative growth stage of the plant.

Relative Leaf Water Content (RLWC)

Relative leaf water content was measured using the method of (Turner, 1981). Leaf discs (9 mm in diameter) were taken using the second fully expanded leaves from the top at 60 days after the start of the treatment. The sample was sealed in glass tube. 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 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 samples were packed in paper bags, and oven dried at 65^0C 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 (1981):

LRWC (%) = [(F.W – D.W) / (T.W – D.W)] * 100

Where: F.W., Fresh weight; D.W., Dry weight; T.W., Turgid weight

Leaf Temperature

Leaf temperature was recorded 30 cm far from well-developed leaf at 4th node from the bottom by using digital infrared thermometer. The readings were taken starting from 12:00 pm at 30 minute intervals and four readings were taken throughout the experiment. The measurements were taken on clear and less cloudy days (Fabio *et al*., 2018).

Leaf Reflectance

Reflectance spectra of the leaves were taken using a spectroradiometer apogee instrument (PS-300 measures a wavelength range of 300 to 1000 nm-21 West 1800 North Logan, UT 84321, United States of America) with AS-003: Reflectance Probe and AS-004 to get a white reference standard. For each leaf, spectral reflectance in range between 220 and 1100 nm at a spectral resolution of 0.5 nm was measured on three randomly collected on the adaxial side of leaf in plant cell laboratory of Hawassa University.

3.6.4. Yield and yield components

Fresh weight of vines per plant (gm):- Fresh weight of 3 randomly selected sweetpotato vines per plant was measured from each treatment by using scale.

Fresh weight of harvested tuberous roots per plant: - The fresh weights of all harvested tuberous roots per plant were measured using measuring scale.

Fresh biomass (gm): - It is the sum total of vines with leaves and tuberous roots per plant measured by scale.

Tuber number: - Number of tuberous root per plant was counted from 3 randomly selected plants in each treatment after harvesting.

3.7. Data Analysis

The parameters considered in this study were subjected to analysis of variance (ANOVA) using General Linear Model in SAS software version 9.3 and mean separation was made based on LSD at 0.5% probability level (SAS institute, 2018). The degree of association between parameters was performed by adopting simple Pearson correlation analysis.

4. RESULTS AND DISCUTION

4.1. Meteorological Data

4.1.1. Air temperature, Relative humidity and Vapour pressure deficit

Mean maximum and minimum air temperature (32.77 ^{0}C and 14.67 ^{0}C) and relative humidity (89.15% and 39.8%) were recorded in the shade house (Table 4). The shadehouse condition was therefore in the range of optimum temperature (21.9 ^{0}C) for vegetative and tuber production for most of sweetpotato varieties (Ramirez, 1992; Qadir and Ali, 1999). Similarly the maximum and minimum (2.99 KPa and 0.18 KPa) vapour pressure deficit were recorded (Table 4). The maximum air temperature and vapour pressure deficit and minimum relative humidity were recorded at 11:18 AM. The result revealed that air temperature and VPD are directly correlated while relative humidity is negatively correlated.

The transpiration rate of the plant is driven by changes in vapour pressure deficit (VPD), which is a combined function of air temperature and relative humidity (Vadez *et al.*, 2014). Water loss from plant shoot results in an increase in the vapour pressure gradient between the ambient air and leaf, and consequently increased transpiration rate. Increasing water loss from the soil also can occur due to vapour pressure rise (Torres-Ruiz *et al.*, 2013). Moreover, transpiration responses to increasing VPD have been affected crop yield under terminal water deficit regimes (Medina *et al.*, 2019).

Stomata close in response to large vapour pressure deficit (the difference between the vapour pressures of the leaf and atmosphere). This mechanism is important to enable plants to control water loss when they exposed to a dry atmosphere (Pirasteh-Anosheh *et al.*, 2016).

Table 4. Shade house climatic data during the experimental period (average of 20 days)

Hour	Temperature (^{0}C)	Relative Humidity (%)	VPD (KPa)
12:18:00 PM	30.22	45.65	2.33
1:18:00 PM	30.68	42.98	2.51
2:18:00 PM	28.64	45.86	2.12
3:18:00 PM	26.04	50.86	1.65
4:18:00 PM	24.32	54.76	1.37
5:18:00 PM	22.03	60.70	1.04
6:18:00 PM	20.38	67.00	0.79
7:18:00 PM	19.67	69.12	0.70
8:18:00 PM	18.73	71.42	0.61
9:18:00 PM	18.05	74.28	0.53
10:18:00 PM	17.58	75.97	0.48
11:18:00 PM	17.17	78.12	0.42
12:18:00 AM	16.68	79.80	0.38
1:18:00 AM	16.28	82.15	0.33
2:18:00 AM	15.87	84.13	0.28
3:18:00 AM	15.38	86.07	0.24
4:18:00 AM	14.92	87.87	0.20
5:18:00 AM	14.67	89.15	0.18
6:18:00 AM	17.00	81.67	0.35
7:18:00 AM	20.50	69.95	0.72
8:18:00 AM	26.60	54.83	1.57
9:18:00 AM	29.70	46.65	2.22
10:18:00 AM	31.52	43.18	2.63
11:18:00 AM	32.77	39.80	2.99
Mean	21.89	65.91	1.11

4.2. Morphological and growth parameters

4.2.1. Branch number, root number, leaf number and leaf area

Analysis of variance revealed that significant influence on branch number; root number, leaf number and leaf area were observed due to the interaction effect of sweetpotato varieties and irrigation interval (Appendix Table I).

The interaction effect of variety and irrigation interval was significantly ($P \leq 0.001$) different on branch number (Table 5). The maximum branch number was measured when variety “Dilla” and “Kulfo” irrigated daily than “NASPOT 12 O”. The branch number of varieties was dropped under prolonged watering interval (from daily to 21 days) by 49.5%, 76.9% and 78.5% in “NASPOT 12 O”, “Kulfo” and “Dilla” varieties, respectively (Table 5). This result indicated that variety “Dilla” was more sensitive to moisture stress than “Kulfo” and “NASPOT 12 O” varieties. Tolerance to moisture stress was largely observed in variety “NASPOT 12 O” than the two varieties. These observations were collaborated with previous findings reporting significant reduction in branch number under water stress condition in sweetpotato (Roro and Tesfaye, 2019). Likewise, the other study, indicated that drought reduced the number of branches per plant in sweetpotato (Saqib *et al.*, 2017).

The maximum root number (13root/plant) was observed from variety “NASPOT 12 O” and “Kulfo” treated with daily irrigation interval. While the minimum root number was observed in Dilla” and “Kulfo” treated with 7 ton 21 days irrigation interval and NASPOT 12 O with 21 days (Table 5). Root number reduced by 61.5%, 48.7% and 23.8% in varieties “Kulfo”, “NASPOT 12 O” and “Dilla” respectively (Table 5). As irrigation interval increased root number reduction was observed in all varieties. This study is related with the finding of Daryanto *et al*. (2016) who stated water scarcity reduced number of adventitious roots that would differentiate into storage roots on cassava plant. Such reduction in root number under water stress condition might be related with reduction in cell division and elongation at root primordia (Amina *et al*., 2014).

Table 5. Interaction effects of sweetpotato variety and irrigation interval on branch number and root number

Irrigation interval (Days)	**Varieties**		
	NASPOT 12 O	**Kulfo**	**Dilla**
Branch number			
Daily	10.56b	15.89a	16.56a
7	7.22de	7.67d	9.44c
14	6.45ef	4.89g	5.44fg
21	5.33g	3.67h	3.56h
LSD	1.11		
CV%	8.12		
Root number			
Daily	13.00a	13.00a	7.00cd
7	9.00b	6.00de	6.33de
14	8.67bc	6.00de	5.67de
21	6.67de	5.00e	5.33de
LSD	1.74		
CV	13.47		

Where, LSD and CV indicate least significance difference and Coefficient of variation, respectively. Means in the same column followed by the same letter are not significantly different at the 5% probability level.

Leaf number reduced among varieties by 90%, 70% and 38.9% in “Kulfo”, “Dilla” and “NASPOT 12 O” varieties, respectively, under prolonged irrigation interval (Table 6). Although the reduction was observed in all varieties, but the effect was stronger in Kulfo than the other varieties. It was observed that “NASPOT 12 O” was strongly tolerant to moisture stress in terms of leaf number than “Dilla” and “Kulfo” varieties. This result is related with the finding of Yooyongwech *et al*. (2014) who reported significant reduction on number of leaves in sweetpotato varieties under lower soil water content.

The maximum leaf area was observed in “NASPOT 12 O” (3212 cm^2) and “Dilla” (2858.1 m^2) variety irrigated daily and the minimum leaf area was in “Kulfo” treated with 21 days irrigation interval (111 cm^2) but which had no significance difference with Kulfo and Dilla varieties at 14 and 21days irrigation interval. Leaf area reduced as irrigation interval increases by 79.9%, 89.3% and 94.3% in “NASPOT 12 O”, “Dilla” and “Kulfo” varieties, respectively (Table 6). The result shows that tolerance to moisture stress was largely observed in variety “NASPOT 12 O” than the two varieties. Plant growth usually decreases as soil water availability becomes more limited due to turgor loss in expanded cells (kirnak *et al.*, 2001). Reducing number and size of leaves is one way of drought tolerant mechanism (Abobatta, 2019). At beginning of water stress, retarding of cell growth, force to a reduction in leaf development and lower leaf surface area that lowers transpiration rate and water uptake. Reduction of leaf area positively related with transpiration and photosynthesis of the plant. Our result shows that, 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. This result is related with the finding of Yooyongwech *et al*. (2013) who states leaf area of 15 cultivars of sweetpotato were decreased when plants exposed to water withholding in the pot culture.

Table 6. Interaction effects of sweetpotato variety and irrigation interval on leaf number and leaf area.

Irrigation interval (Days)	**Varieties**		
	NASPOT 12 O	**Kulfo**	**Dilla**
Leaf number			
Daily	78.67de	251.00a	174.00b
7	68.33de	129.00c	98.67cd
14	54.67ef	42.33ef	70.00de
21	48.00ef	25.00f	52.67ef
LSD	39.42		
CV%	25.57		
Leaf area(cm^2)			
Daily	3212.0a	1978.5b	2858.1a
7	1070.9c	966.5cd	1086.5c
14	885.9cd	179.5f	438.8ef
21	645.7de	111.0f	304.7ef
Decrease in %	79.9	94.3	89.3
LSD	243.94		
CV	21.79		

Where, LSD and CV indicate least significance difference and Coefficient of variation, respectively. Means in the same column followed by the same letter are not significantly different at the 5% probability level.

4.2.3. Vine length and Internode length

The result indicates that vine length significantly ($P \leq 0.001$) responded to effect of varieties and in the contrary, there was no significant difference in terms of internode length due to the effect of varieties but vine length and internode length significantly affected by irrigation interval (Appendix Table I, II). Variety "Dilla" showed higher value in vine length (41.92 cm) and internode length (1.85 cm) and the minimum vine length (18.5 cm) was from "NASPOT 12 O" whereas, internode length was recorded from "NASPOT 12 O" and "Kulfo" variety (Table 7). The maximum vine length and internode length was measured from daily irrigation interval (Table 7). However, vine length and internode length significantly reduced under prolonged watering interval (from daily to 21 days) by 78.6% and 83.9% respectively (Table 7).

The reduction of vegetative growth under water stress is one way of morphological adaptation strategy (Abobatta, 2019). This finding collaborated with the finding of Heerden and Laurie (2008), which stated vine length reduction in sweetpotato under lower field capacity than well watering. Likewise, in another study, sever water stress had profound effect on vine length and Internode length of sweetpotato (Esan *et al*., 2018). Vine length significantly reduced as the plants were subjected to slight and severe water stress as compared to plants at no water stress (Yooyongwech *et al*., 2014).

Table 7. Effects of sweetpotato variety and irrigation interval on vine length (cm), and internode length (cm)

Treatment	**Vine Length (cm)**	**Internode Length(cm)**
Varieties	***	ns
NASPOT 12 O	18.5^{b}	1.61^{ab}
Kulfo	37.83^{a}	1.5^{b}
Dilla	41.92^{a}	1.85^{a}
LSD (5%)	7.5522	0.32
Irrigation interval(I)	*	***
Daily	40.78^{a}	2.33^{a}
7 Days	33.44^{ab}	1.63^{b}
14 Days	31.33b	1.39^{b}
21 Days	25.44b	1.26^{b}
LSD (5%)	8.72	0.38
CV (%)	27.24	23.21

Where, LSD and CV indicate least significance difference and Coefficient of variation, respectively. Means in the same column followed by the same letter are not significantly different at the 5% probability level.

4.3. Physiological Responses

4.3.1. Chlorophylls concentration (µg ml-1)

Chlorophylls concentration (chla, chlb and TC) was significantly ($P > 0.01$) influenced by main factors and interaction of varieties and irrigation interval (Appendix Table II). Maximum chlorophyll concentration (chla, chlb and TC) recorded from were variety “NASPOT 12 O” treated with daily irrigation. On the other hand, the minimum chlorophylls concentration (chla and TC) was obtained from were variety “Kulfo” and treated with 21 days irrigation interval and chlb from Kulfo and Dilla with 21 days irrigation interval (Table 8).

Chlorophyll a (Chla), chlorophyll b (Chlb) and total chlorophyll (TC) contents in the leaf tissues of sweetpotato varieties subjected to seven to twenty-one days irrigation interval declined significantly over that of daily irrigation (Table 8). The reduction in chlorophyll content in our study also might be regarded as a drought response mechanism associated with minimization of light absorption by chloroplasts (Herbinger *et al*., 2002). Sweetpotatoes were unable to meet their metabolic requirements and have ultimately disturbed the physiological functioning of the whole plant by chlorophyll-deficient caused by water stress (Saraswati, 2007).

The present study corroborated with study reported by Yooyongwech *et al*. (2014) who stated that, the concentration of chlorophyll (chla, chlb and TC) contents in the leaf tissues of sweetpotato varieties subjected to moisture deficit 8-15% Soil Water Content declined significantly reduced as compared to well-watered plant. Similarly, different researchers demonstrated that plant exposed to water deficit significantly reduced chla, chlb and TC in different plants (Massacci *et al*., 2008; Farooq *et al*., 2009; Fabio *et al*., 2018).

The decrease in chlorophyll concentration under drought stress could be due to the result of damage to chloroplasts caused by active oxygen species (Smirnoff, 1995; Anjum *et al*., 2011). Moisture stress also affects Chlorophyll content by affecting chlorophyll components (IturbeOrmaetxe *et al*., 1998).

Nozipho (2015) also reported a reduction of all chlorophylls chla, chlb and TC at high water stress. This reduction was reported to be associated with an increase in electrolyte leakage caused by leaf senescence and reduced water use in plants.

However, in our case the decrease in chlorophyll content under moisture stress has been considered as a typical symptom stress in which the chlorophyll fluorescence measured in all varieties was lower under longer irrigation interval (<0.8 Fv/Fm) than daily, seven and fourteen days interval (Figure 1) and probably due to oxidative stress and pigment photo-oxidation and chlorophyll degradation (Herbinger *et al*., 2002).

Table 8. Interaction effects of sweetpotato variety and irrigation interval on concentration of chlorophyll a (chla), chlorophyll b (chlb) and total chlorophyll (TC)

Variety	**Irrigation interval**	**Chla (μg ml^{-1})**	**Chlb (μg ml^{-1})**	**TC (μg ml^{-1})**
NASPOT 12 O	Daily	180.25^{a}	137.57^{a}	317.82^{a}
	7days	164.56^{d}	124.29^{bcd}	288.85^{d}
	14 days	146.4^{f}	112.34^{e}	258.75^{f}
	21 days	130.51^{h}	103.55^{f}	234.06^{g}
Kulfo	Daily	170.61^{c}	127.74^{bc}	298.34^{c}
	7days	164.17^{de}	121.32^{d}	285.49^{d}
	14 days	144.99^{fg}	109^{ef}	253.98^{f}
	21 days	112.30^{j}	95.52^{g}	207.83^{i}
Dilla	Daily	175.81^{b}	130.24^{b}	306.05^{b}
	7days	161.77^{e}	124.05^{bcd}	285.81^{d}
	14 days	143.41^{g}	122.74^{cd}	266.15^{e}
	21 days	121.12^{i}	93.08^{g}	214.2^{h}
LSD		2.74	6.22	6.21
CV		1.07	3.15	1.37

Where, chl a=concentration of chlorophyll a, chl b= concentration of chlorophyll b, chl (a+b) = concentration of total chlorophyll, and means with different letter in each columns are statistically significant at P-values < 0.05.

4.3.2. Chlorophyll florescence parameter measurement

Maximum quantum yield of PSII (Fv/Fm) was significantly ($P \leq 0.001$) affected by main factors and interaction of varieties and irrigation interval (Appendix Table III). Figure 1 showed that the maximum quantum yield of PSII (Fv/Fm) was observed from daily irrigation while the minimum value was observed from 21 days irrigation interval. Fv/Fm declines with extended irrigation interval.

There was no significant difference between daily and 7 days irrigation interval. Moreover, there was no significance difference with Seven days and fourteen days watering interval in the value recorded Fv/Fm in “NASPOT 12 O” and “Dilla” varieties but there was significance difference between “Kulfo” treated with 7 days and 14 days irrigation interval in terms of Fv/Fm (Figure 1). The highest Fv/Fm was observed from daily and seven days irrigation interval with all variety while the least was observed from variety “Dilla” treated with twenty-one days watering interval. This might be due to genetic information contributed for the maximum quantum yield respond to express its genetic potential under different level of stress. Previous report indicated that variability in Fv/Fm help to screen variety resistant to biotic and abiotic stress factors (Pozo, *et al.*, 2020).

This result related with the finding of Yooyongwech *et al*. (2013) who stated reduction of maximum quantum yield abilities under water stressed varieties than well watered sweetpotato varieties. Xuejuan *et al*. (2018) in maize and Shahenshah and Isoda (2010) in cotton and peanut crops also discussed that maximum quantum yield significantly decreased under water stress than normal watering condition. The reduction of chlorophyll florescence and photosynthetic pigments directly affects photosynthesis (Kirnak *et al*., 2001; Saraswati, 2007). The reduction of Fv/Fm indicates that the PSII reaction center of the sweetpotato leaves had been damaged by drought stress, and their potential activity and primary light energy conversion efficiency were obviously weakened, so photoinhibition of photosynthesis occurred in the plants (Hazrati *et al*., 2016).

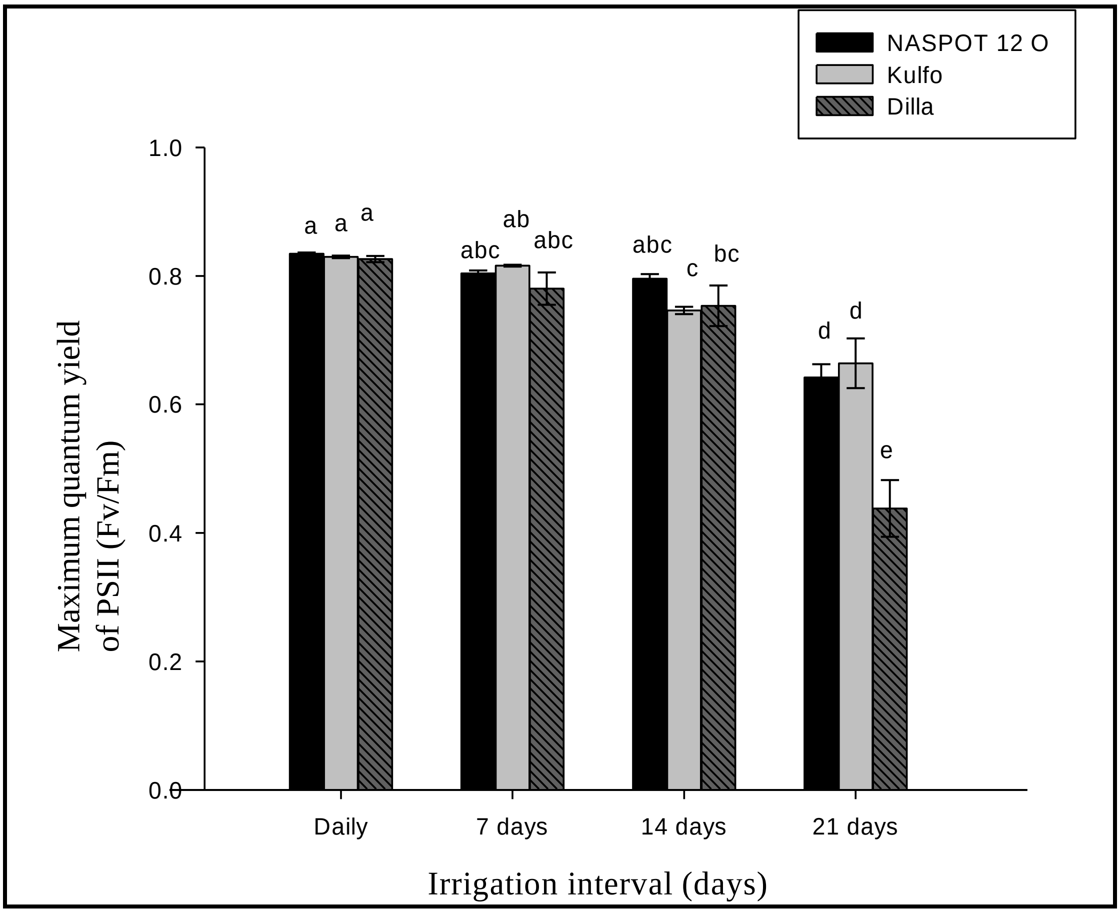

Figure 1. Interaction effects of sweetpotato variety and irrigation interval on maximum quantum yield of PSII (Fv/Fm). While, means with different letter on the figure are statistically significant at *P*-values < 0.05, LSD (0.05), = 0.0643 and CV (%) = 5.10

4.3.3. Proline concentration

Proline content was significantly ($P \leq 0.01$) affected due to the two main factors and their interaction (Appendix Table III).

Proline concentration increases with increasing water stress on variety "NASPOT 12 O''. But no significant difference was seen on variety "Kulfo" and "Dilla" with prolonged watering interval (Table 9). The maximum proline content was observed from variety "NASPOT 12 O" with 21 days following fourteen days irrigation interval whereas, the minimum was observed from the rest treatments which were not significantly different (Table 9). Yooyongwech *et al.* (2016), has been reported that free proline accumulation at the cellular level play a key role in osmotic adjustment, which promotes drought defense mechanisms. In this study the higher accumulation of proline content with "NASPOT 12 O" variety probably a good indication for moisture stress tolerance as compared to "Kulfo" and "Dilla". During drought stress, proline plays an important role and acts as a signaling compound to regulate mitochondria function and affect cell proliferation by means of activating particular genes, which are essential for stress recovery (Szabados and Savoure, 2009). In addition, accumulation of proline under stress condition in many plant species has been correlated with stress tolerance, and its concentration has been shown to be generally indication of stress-tolerant plants (Anjum *et al*., 2011).

This result is related with the finding of Yooyongwech *et al*. (2014) who reported that the accumulation of proline content in sweetpotato directly related with increasing in moisture stress. The accumulation of higher level of proline in "NASPOT 12 O" in this study (Table 9) might be the potential of the variety to improve the effects of moisture stresses; through accumulation of compatible osmolytes such as proline to improve the uptake of moisture from the soil. According to Rodriguez-Delfin *et al*. (2012) observation free proline content increased significantly when plants were subjected to water deficit under soilless culture.

Table 9. Interaction effects of sweetpotato variety and irrigation interval on proline concentration

Variety	**Irrigation interval**	**Proline (μg.gm^{-1}FW)**
NASPOT 12 O	Daily	0.30^{bc}
	7days	0.30^{bc}
	14 days	0.47^{b}
	21 days	0.95^{a}
Kulfo	Daily	0.24^{c}
	7days	0.24^{c}
	14 days	0.26^{c}
	21 days	0.35^{bc}
Dilla	Daily	0.22^{c}
	7days	0.21^{c}
	14 days	0.26^{c}
	21 days	0.35^{bc}
LSD		0.17
CV		28.60

Where, LSD and CV indicate least significance difference and Coefficient of variation, respectively. Means with different letter in each column are statistically significant at P-values < 0.05.

4.3.4. Stomata number

The result revealed that stomatal number was significantly ($P \leq 0.05$) affected by varieties but not significantly affected by irrigation interval and interaction of the main factors (Appendix Table III). The maximum stomata number was observed from variety “NASPOT 12 O” and “Dilla” while the minimum value was observed from variety “Kulfo” (Table 10).

Water stress did not affect stomatal number in all varieties used in the present study. Variety “Dilla” and “NASPOT 12 O” had significantly greater stomatal number than variety “Kulfo” this may be the reason for “NASPOT 12 O” and “Dilla varieties had higher transpiration and photosynthesis rate (Figure 2 and 3). This result confirmed with the finding of Saraswati (2007) who stated that stomatal number of the sweetpotato cultivars (Lole and Wanmun) was not influenced by soil water stress conditions. Similarly, Roro and Tesfaye (2019) reported stomata number was not significantly affected by moisture stress in sweetpotato varieties.

Table 10. Effects of sweetpotato variety and irrigation interval on stomata number

Treatment	Stomata number (mm^2)
Varieties	*
NASPOT 12 O	12.75^{a}
Kulfo	11.33^{b}
Dilla	12.41^{a}
LSD (5%)	0.43
Irrigation Interval	ns
Daily	12.44^{a}
7 Days	12.22^{ab}
14 Days	12.10^{ab}
21 Days	11.88^{b}
LSD (5%)	0.5
Interaction	ns
CV (%)	4.23

Where, LSD and CV indicate least significance difference and Coefficient of variation, respectively. Means in the same column followed by the same letter are not significantly different at the 5% probability level

4.3.5. Leaf gas exchange parameters

Analysis of variance showed that gas exchange parameters [(Photosynthetic rate (µmol m-2s-1), Transpiration rate (mmol m-2s-1) and Stomatal conductance (mmol m-2s-1)] were significantly affected by main and interaction effect of variety and irrigation interval (Appendix Table IV).

Photosynthesis (A) µmol m-2s-1

The maximum assimilation was observed from interaction of "NASPOT 12 O" followed by "Dilla" and "Kulfo" with daily irrigation. However, photosynthesis rate significantly decreased in all varieties as irrigation interval extended to 21 days interval (Figure 2). The reduction in all varieties was stronger under 21 day's irrigation interval (Figure 2). This indicated that plant adaptability to water deficit inhibit photosynthesis rate uniformly acting on stomata regulation and limiting flow of CO_2 into mesophyll tissues and also by impair the activity of ribulose-1,5-bisphosphate carboxylase/oxygenase in all plant species (Figure 2,4). Mutava *et al*. (2015) reported photosynthesis rate affected by Stomatal closure in response to drought stress. However, the response of plants to stresses depends on species and varieties, the length and severity of water deficit, and age and development stage (Shinozaki *et al*., 2007).

Similarly, when water stress increases photosynthetic abilities decrease due to reduced photosynthetic pigments and limited CO_2 assimilation through stomatal pore although leaf transpiration and cell water potential decreases; which had conformities with previous findings in sweetpotato (Heerden *et al*., 2008; Yooyongwech *et al*., 2014) and in Grapevines (Gomez *et al*., 2002).

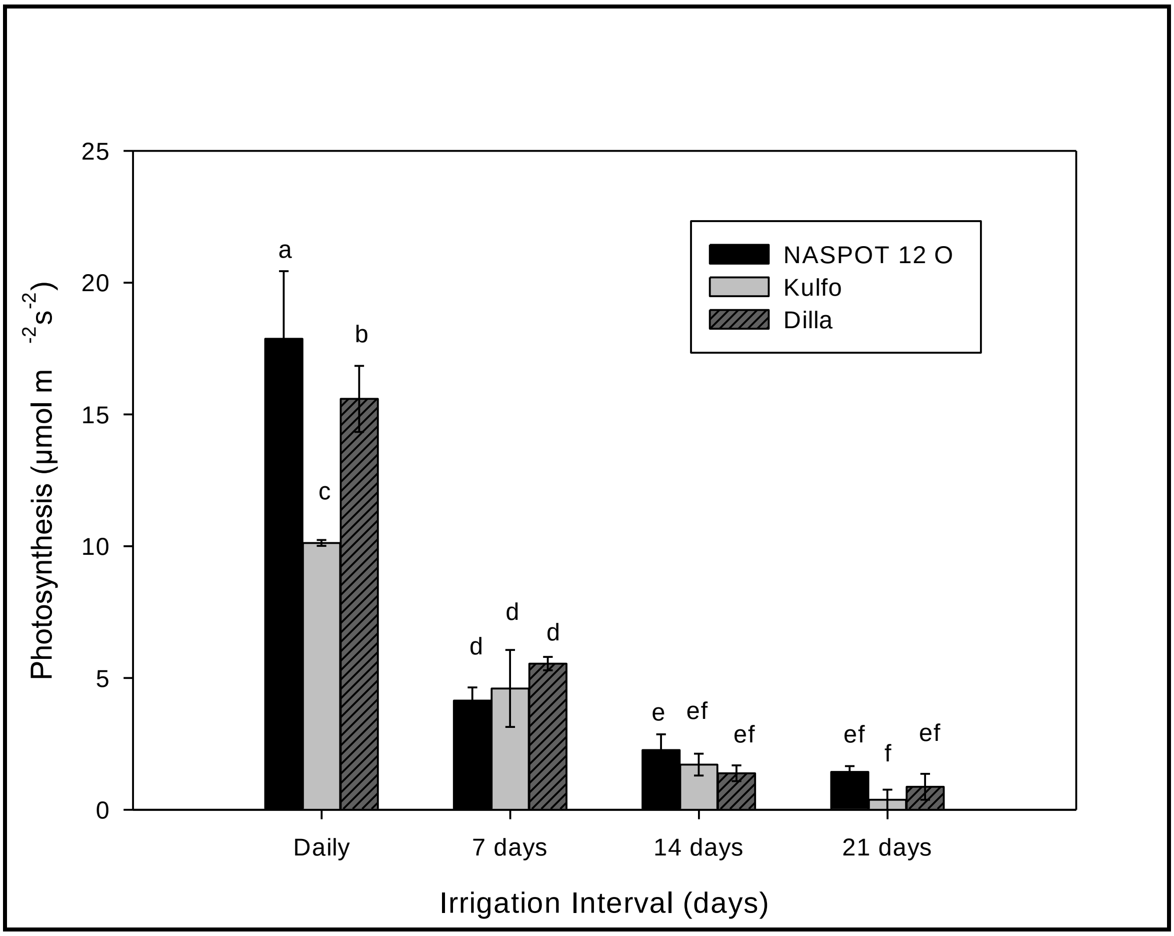

Figure 2. Interaction effects of sweetpotato variety and irrigation interval on photosynthesis rate. While, means with different letter on the figure are statistically significant at *P*-values < 0.05, LSD (0.05), = 1.4507 and CV (%) = 15.60.

Transpiration (E) mmol m-2s-1

The study revealed that transpiration was significantly ($P \leq 0.01$) affected by main effects and interaction of varieties and irrigation interval (Appendix Table IV). Transpiration also decreases with increasing water stress (Figure 3). The maximum transpiration rate was observed from “NASPOT 12 O” with daily irrigation followed by “Dilla” and “Kulfo” with daily irrigation interval. The minimum moisture loss through transpiration was recorded in all varieties when irrigation interval was extended to 14 and 21 days. It was observed that extending irrigation interval to 21 days significantly decreased transpiration rate by 73.4%, 64% and 57.2% in “NASPOT 12 O”, “Dilla” and “Kulfo”. Such reduction in transpiration might be related with reduction in stomata conductance. Moreover, the reduction in transpiration rate also related with reduction in gas exchange due to change in stomata movement. Report indicated that, stomata are the main channels for plants to affect exchange water and gas with the environment within the main photosynthetic organs and are closely correlated with plant physiological activities such as photosynthesis, respiration, and transpiration (Franks and Beerling, 2009; Taylor *et al*., 2010).

The result confirmed with the finding of Saraswati (2007) who stated, transpiration rate decreases with increasing moisture stress. The reduction of transpiration rate with increased drought could be due to the reduced amount of water in the cell which leads turgor loss and closure of stomata. Reducing transpiration rate by keeping stomata closed under moisture stress condition is one way of dehydration avoidance (Anjum *et al*., 2011).

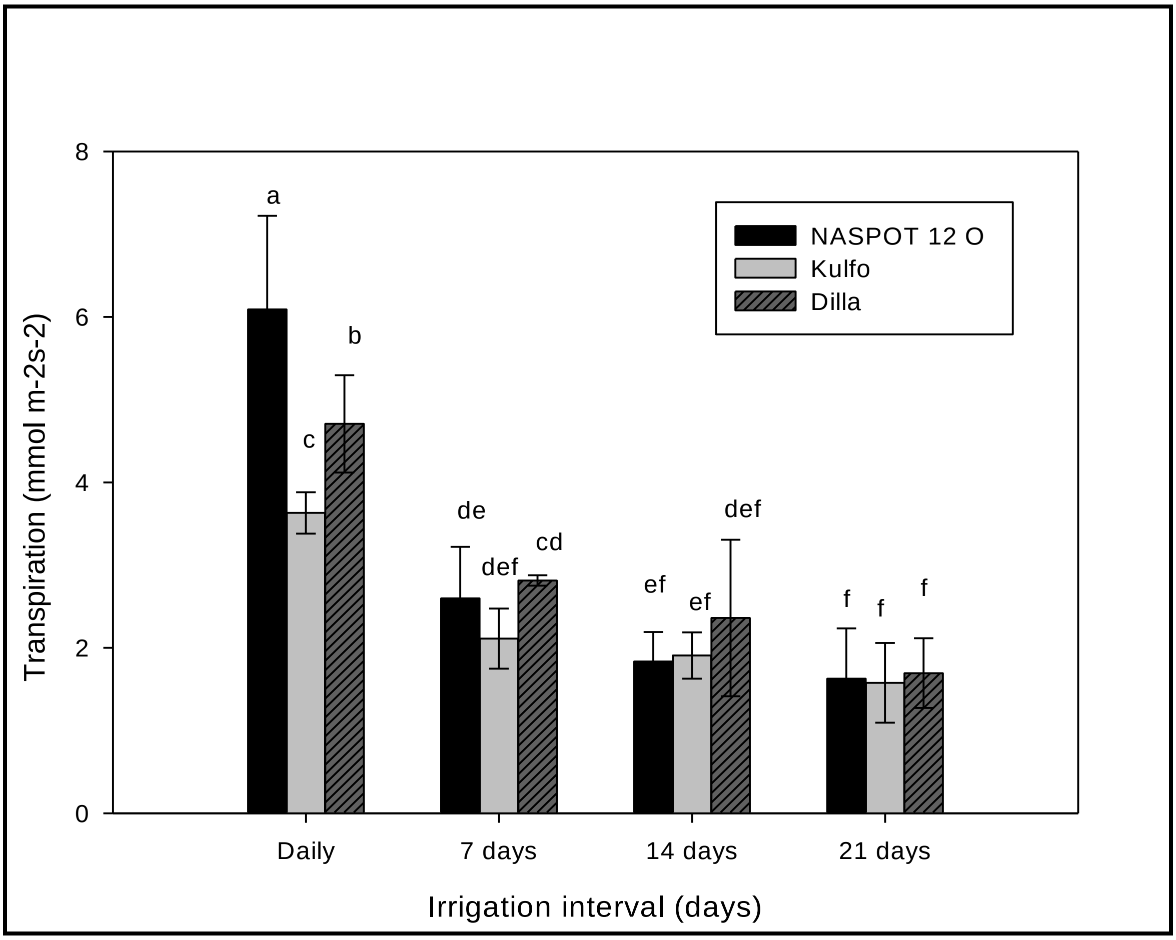

Figure 3. Interaction effects of sweetpotato variety and irrigation interval on transpiration rate. While, means with different letter on the figure are statistically significant at *P*-values < 0.05, LSD (0.05), = 2.7453 and CV (%) = 18.28

Stomatal Conductance (g_s) mmol $m^{-2}s^{-1}$

The result indicated that, stomatal conductance of different sweetpotato variety has significantly ($P \leq 0.001$) influenced by main effect and their interaction (Appendix Table IV). As irrigation interval extended the rate of stomatal conductance also significantly decreased and the reduction was stronger when each variety was subjected to 21 days of irrigation interval as compared to daily irrigation.

The maximum stomatal conductance was observed from variety “NASPOT 12 O” treated with daily irrigation (Figure 4). However, with extended irrigation interval to 21 days the stomata conductance was significantly reduced in all varieties, but the reduction was stronger when each variety was irrigated with 14 days and 21 days of irrigation interval (Figure 4). Previous report indicated that a severe decline in stomatal conductance values for sweetpotato plants related with plant exposed to drought stress (Heerden and Laurie, 2008 and Yooyongwech *et al*., 2013). Such reduction in gas exchange during moisture stress might be the strategy for plant to reduce moisture loss. Similar observation also investigated by (Arve *et al*., 2011), who reported that plant reduced stomata conductance has a potential to reduce water loss through transpiration and this can be mechanism to tolerate drought than plant failed to regulate stomata conductance. The reduction in stomatal conductance was correlated with an increase in the water use efficiency, which indicates that stomatal closure contributed to optimizing water use efficiency in plants under stress (Wei *et al*., 2018).The drying out of soil and leaf water potential influence stomatal conductance by reduction of turgor pressure in root cells which influence the production of ABA by roots and their transport to leaves. Other recent evidence suggests leaf ABA may also affect leaf hydraulic conductance, which could amplify changes in leaf turgor sensed by stomata (Thomas, 2017).

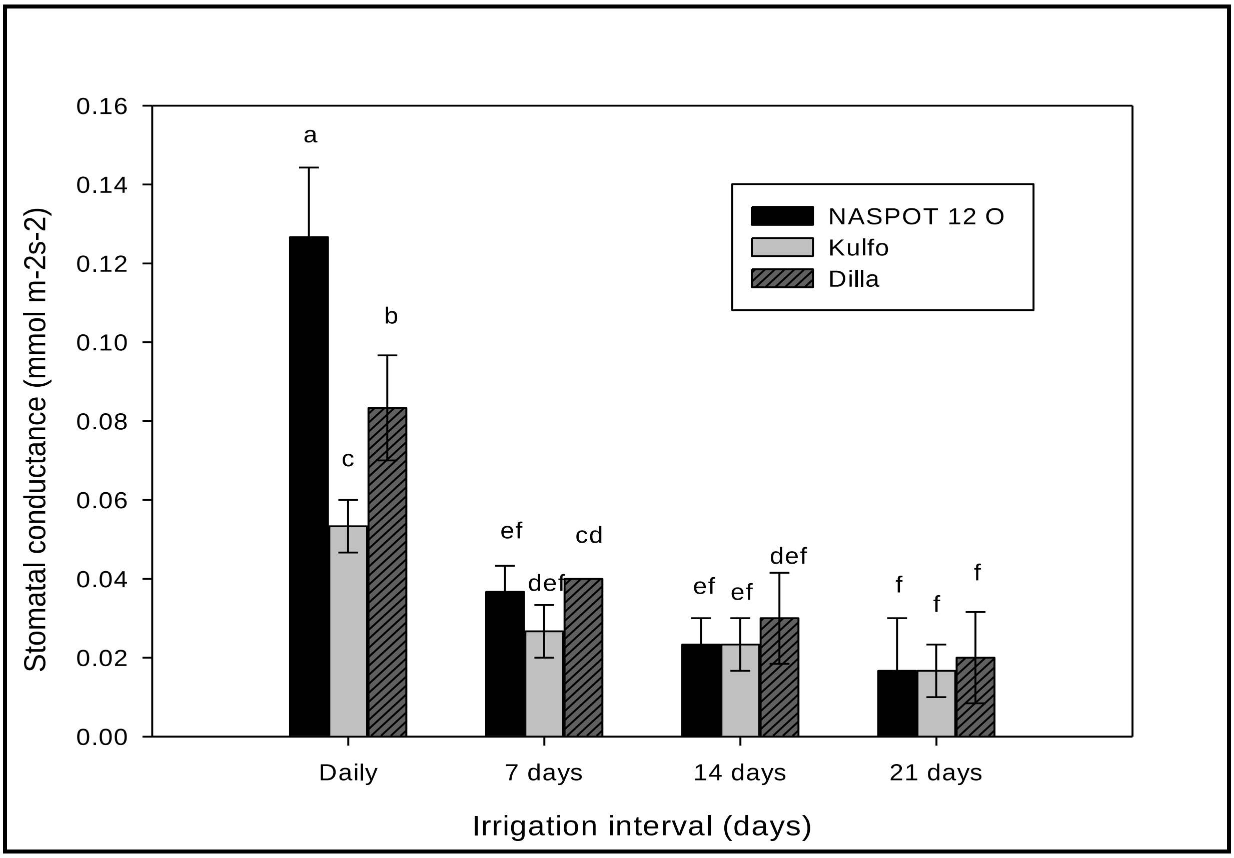

Figure 4. Interaction effects of sweetpotato variety and irrigation interval on stomatal conductance. While, means with different letter on the figure are statistically significant at *P*-values < 0.05, LSD (0.05), = 0.0146 and CV (%) = 20.78.

4.3.6. Instantaneous Water use efficiency (IWUE)

The analysis of variance revealed that IWUE recorded in sweetpotato was significantly (*P* ≤ 0.01) affected by irrigation interval and interaction between main factors (Appendix table IV). The maximum IWUE was observed from variety “Dilla” treated with daily irrigation whereas the lowest was observed from variety “Kulfo” treated with 21 days irrigation interval which haven’t Stastical difference with variety Dilla treated with 14 and 21 days irrigation interval (Figure 5). Daily irrigation had significant deviation on IWUE from seven, fourteen and twenty one day’s irrigation interval respectively (Appendix Table V).

Variety “Kulfo” had significant difference in all irrigation intervals and variety “Dilla” had no significant difference between fourteen days and twenty-one days irrigation interval. Variety “NASPOT 12 O” had no significant difference between fourteen and twenty one days irrigation interval (Figure 5). This result shows that variety “NASPOT 12 O” and “Dilla” had more IWUE, this might be the higher leaf area (Table 6) and photosynthetic rate (Figure 2) character of variety “NASPOT 12 O” and “Dilla’ varieties leads it with high water use efficient variety. Whereas, “Kulfo” was the most water consuming variety compared to the two varieties. Instantaneous water use efficiency was diminished with prolonged irrigation interval in all varieties (Figure 5). In line with this finding Boutraa *et al.* (2010) reported that Instantaneous water use efficiency in wheat cultivars declined significantly when plants were subjected to drought stress. Additionally, Fabio *et al*. (2013) revealed that in sweetpotato WUE increases with increasing water depth and decreases with decreasing water depth. Under adequate water; photosynthesis resulted higher because of the greater CO_2 diffusion through stomata, which remain open longer in these conditions while photosynthesis and transpiration decreases by closing of stomata in response to water deficits (Yooyongwech *et al.*, 2013). This might be the reason for less water use efficiency in water stressed condition.

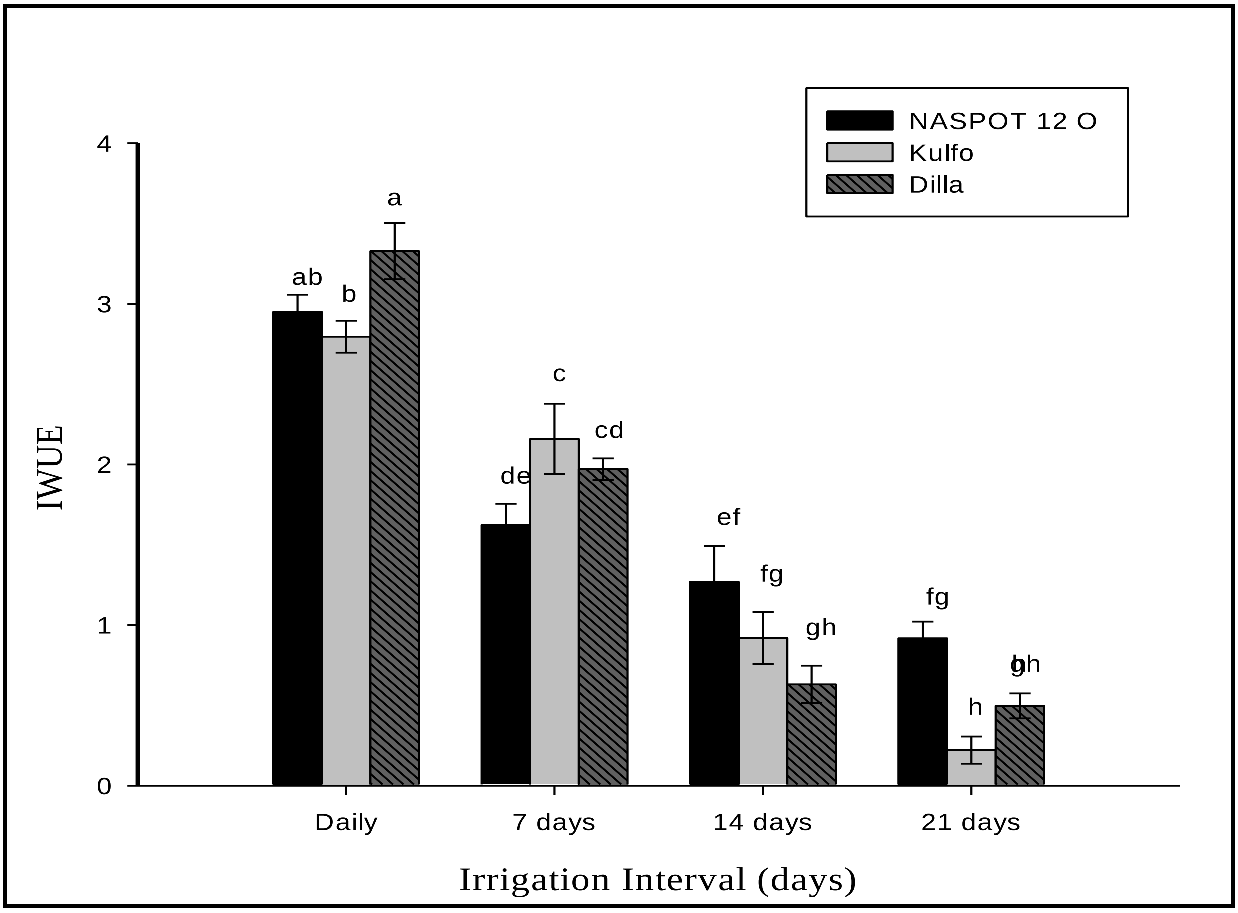

Figure 5. Interaction effects of sweetpotato variety and irrigation interval on instantaneous water use efficiency. While, means with different letter on the figure are statistically significant at *P*-values < 0.05, LSD (0.05), = 0.427 and CV (%) = 15.71

4.3.7. Relative leaf water content (RLWC)

Relative leaf water content of sweetpotato was significantly ($P \leq 0.001$) affected by main factors and interaction of variety and irrigation interval (Appendix table IV).

The result indicated that the highest relative leaf water content were found from variety “NASPOT 12 O” and “Kulfo” when exposed to daily watering condition, while strong reduction in relative leaf water content was observed in variety Kulfo when irrigation interval was extended to 21 days (Figure 6). Similarly, extending irrigation interval from seven days to 21 days did not significantly influenced relative water content of Dilla variety as compared to the other two varieties but still there is no significant difference between variety Dilla and NASPOT 12 O at extended irrigation interval. This indicated that variety Kulfo were more sensitive than the two varieties.

In line with this finding, Saraswati *et al.* (2013) stated that relative water content declined with lower soil water content in sweetpotato. Moreover, Boutraa *et al*. (2010) reported that cultivars of wheat under water stress showed a decrease in the relative leaf water content. The reduction of water potential may induce osmotic adjustments in plants to promote leaf hydration and the production of hormones to adapt to this condition. Recent proof suggests that the leaf water potential increased exponentially with rising water availability in the soil (Fabio *et al*., 2018).

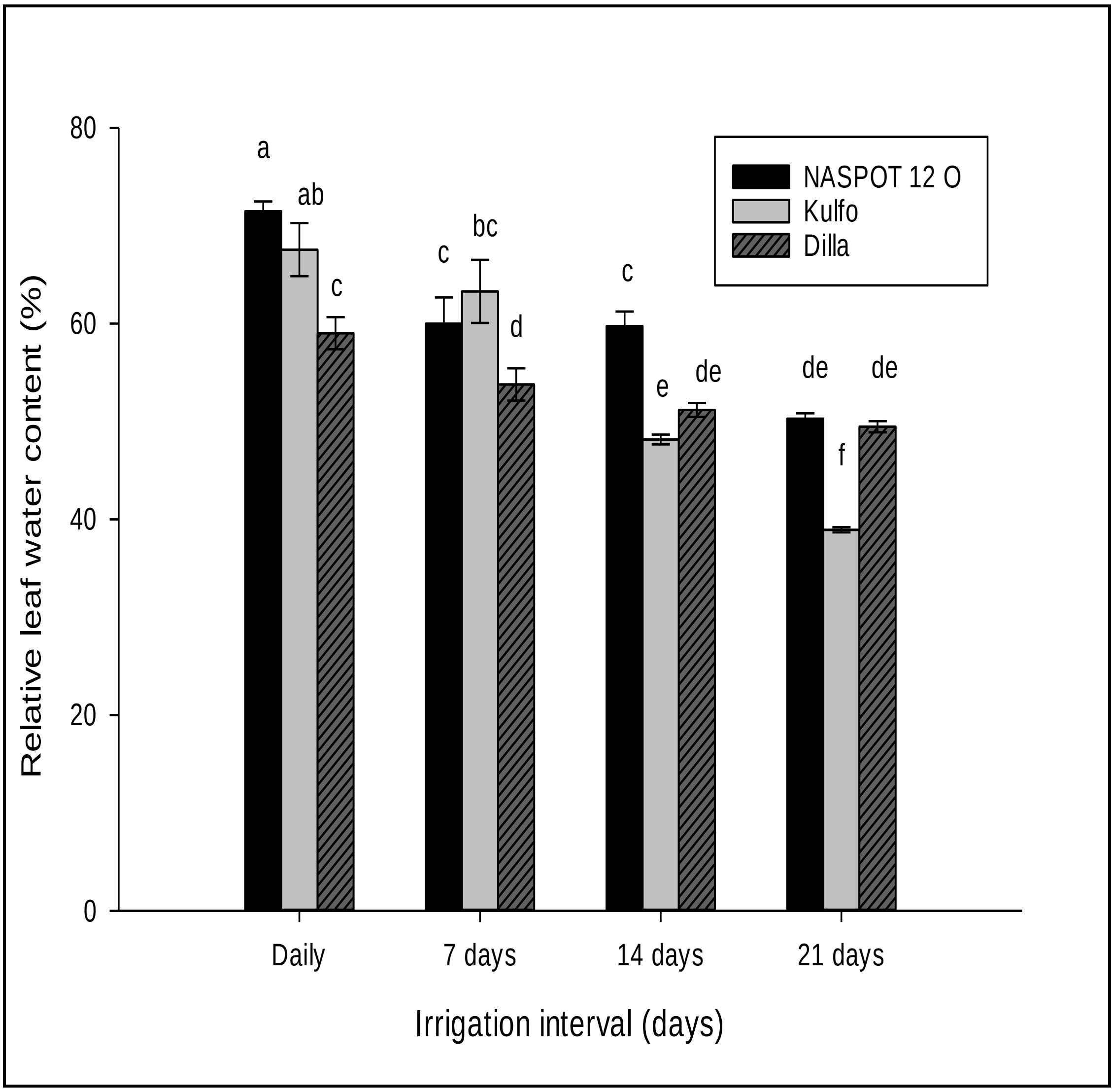

Figure 6. Interaction effects of sweetpotato variety and irrigation interval on relative leaf water content. While, means with different letter on the figure are statistically significant at *P*-values < 0.05, LSD (0.05), = 4.8326 and CV (%) = 5.09

4.3.8. Leaf temperature

The result indicated that leaf temperature had significant ($P \leq 0.001$) difference between main effects but there was no significant difference in terms of their interaction (Appendix Table V). Variety “NASPOT 12 O” had lower leaf temperature than “Kulfo” and “Dilla”. A lower leaf temperature in drought stressed plant indicates a better capacity for taking up soil moisture and for maintaining better plant water status (Blum, 2009). This result shows variety “NASPOT 12 O” was more adaptive to moisture stress than the two varieties.

Leaf temperature rises with prolonged irrigation interval (from daily to twenty-one days irrigation interval) by 17.7% (Table 13). Leaf temperature with 21 days irrigation interval were higher than the mean ambient temperature, by 8.48, 8.04 and 6.63 °C for “Kulfo”, “Dilla” and “NASPOT 12 O” varieties, respectively. This finding related with the finding of Fabio *et al.* (2018) which confirmed leaf temperature increased with lower watering in sweetpotato varieties. Halder and Burrage (2003) also stated that leaf temperature increases with increasing water stress in rice crop.

Decreasing stomatal conductance under limited water availability conditions increases Leaf temperature. Stomata affected by lower water absorption which reduce transpiration and increases leaf temperature (Blonquist *et al*., 2009). Effective transpiration control and faster water movement in plants at high temperatures involves a cooling system, which protects metabolic processes (Sermons *et al*., 2012).

Table 11. Effects of sweetpotato variety and irrigation interval on leaf temperature

Treatment	Leaf temperature
Varieties	***
NASPOT 12 O	28.52^{b}
Kulfo	30.37^{a}
Dilla	29.93^{a}
LSD (5%)	0.75
Irrigation interval	***
Daily	26.14^{d}
7 Days	29.79^{c}
14 Days	30.7^{b}
21 Days	31.78^{a}
LSD (5%)	0.86
Interaction	ns
LSD	1.49
CV (%)	2.98

Where, ns, LSD and CV indicate non significant, least significance difference and Coefficient of variation, respectively. Means in the same column followed by the same letter are not significantly different at the 5% probability level.

4.3.9. Leaf reflectance

The result indicated that sweetpotato variety treated with different irrigation interval had different leaf reflectance property (Figure 7). It was observed that increasing irrigation interval from daily to 21 days significantly increased in green and red bands for Kulfo variety as compared to control (daily irrigation). The difference might be related with the variability in chlorophyll content with deferent varieties. Chlorophyll and other pigments absorb electromagnetic radiation strongly in the visible (400-700nm) wavelengths; thus, plant with higher chlorophyll content will have lower reflectance in these regions (Amatya *et al.*, 2012).

The maximum reflectance observed with Kulfo Variety might be due to lower chlorophyll a, b and total chlorophyll recorded (Table10). Similarly, relationships between spectral reflectance and leaf water content can be either direct or indirect and they are wavelength dependent (Carter, 1993). The reflectance from an individual leaf in the middle infrared region (950-970nm) is largely governed by moisture content of leaves; water absorption is the direct cause for this spectral response (Penuelas *et al.*, 1993). In this study it was observed that an increase with irrigation interval the leaf reflectance in the near infra-red (NIR) region significantly reduced in all varieties as compared to control (Figure 7A, 7B, 7C and 7D). However, strong reduction was observed in Dilla than other varieties.

Different report indicated that, the reflectance of healthy plant is higher at NIR region (Zhou *et al.*, 2011). In this study it was observed that as moisture stress increased due to irrigation interval, the leaf reflectance at NIR region significantly reduced in all varieties, as compared control, and strong reduction in leaf reflection with Dilla variety might be due to lower leaf water content (Figure 6 and 7). Plant with health leaf normally has higher leaf reflectance at NIR region. In this study we observed that with increasing moisture lower and higher reflectance was recorded in Dilla and NASPOT 12 O variety, respectively, it is suggesting that Dilla has un health leaf than NASPOT 12 O variety (Figure 7 A and B). From this it can be observed that NASPOT 12 O variety has a potential to maintain higher leaf water content under moisture stress condition than others and Dilla is more sensitive to moisture stress than others. Plants at different nutrient and water stresses may present different spectral signatures when they are exposed to an electromagnetic spectrum. A plant under water stress will show increase in reflectance in green and red bands and the reflectance in NIR band will decrease compared to healthy plants (Kim *et al*., 2010).

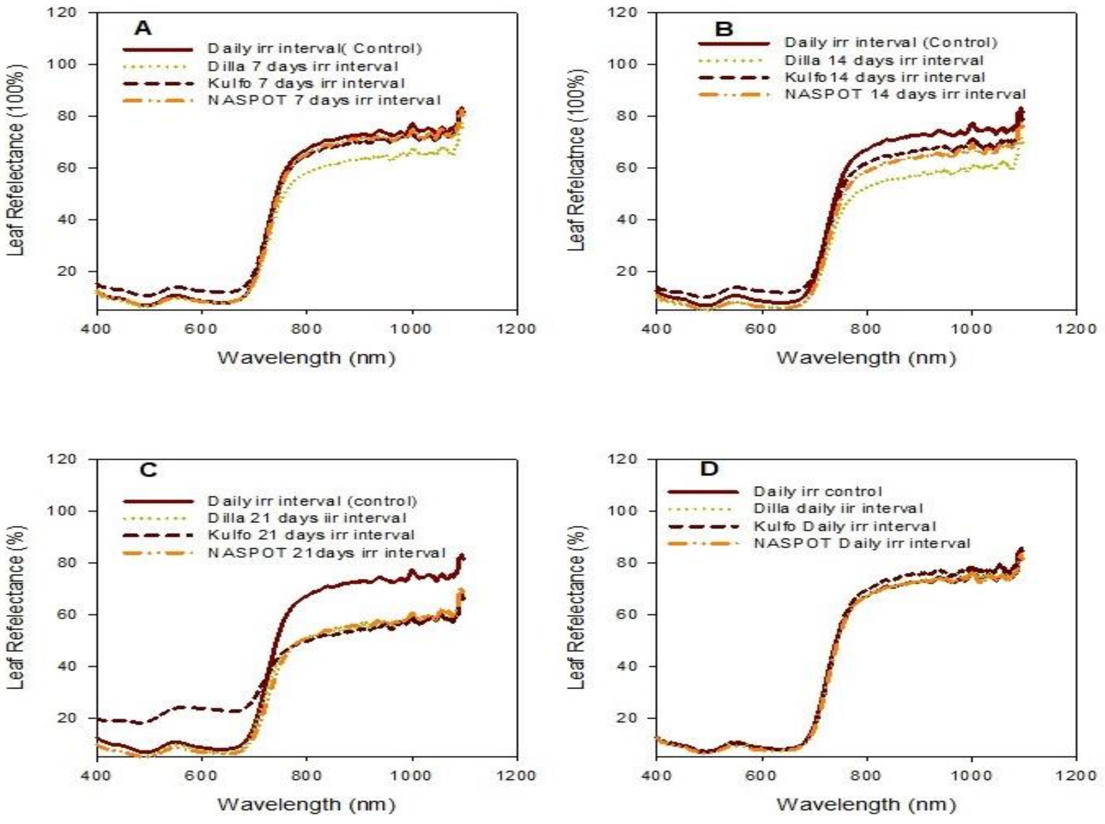

Figure 7. Reflectance from leaves of sweetpotato varieties (Dilla, Kulfo and NASPOT 12 O) irrigated daily-D, 7 days-A, 14 days-B and 21 days-C interval under shade house condition.

4.4. Yield and Yield Components

4.4.1. Vine fresh weight, Tuber fresh weight and Biomass fresh weight

Different varieties, water stress and their interaction had a significant ($P \leq 0.001$) influence on vine fresh weight, tuber fresh weight and biomass fresh weight. Except, vine fresh weight not affected by interaction of the two main factors (Appendix Table V).

As indicated in the result variety "NASPOT 12 O" showed higher value (375 g) while the minimum vine fresh weight (241.67 g) was recorded from variety "Kulfo" (Table 12). The result also revealed that vine fresh weight was diminished with elongated irrigation interval from daily to twenty one days by 355.56 g (83.3%). This finding related with result of Yooyongwech *et al*. (2013) who stated vine fresh weight reduction with increased water stress in sweetpotato varieties.

Table 12. Effects of sweetpotato variety and irrigation interval on vine fresh weight (g)

Treatment	Vine fresh weight (g)
Varieties	***
NASPOT 12 O	375.00^a
Kulfo	241.67^c
Dilla	308.33^b
LSD (5%)	62.094
Irrigation Interval	***
Daily	488.89^a
7 Days	322.22^b
14 Days	288.89^b
21 Days	133.33^c
LSD (5%)	71.7
CV (%)	27.24

Where, LSD and CV indicate least significance difference and Coefficient of variation, respectively. Means in the same column followed by the same letter are not significantly different at the 5% probability level.

The maximum tuber fresh weight (700 g) was obtained from variety “NASPOT 12 O” treated with daily irrigation and the least (0 g) from “Kulfo” treated with 21days interval (Table 13). Total tuber fresh weight decreased by 81.24%, 85.7% and 100% with prolonged irrigation interval on variety “Dilla”, “NASPOT 12 O” and “Kulfo” respectively (Table 13). Depending on this result variety “Dilla” more tolerant to drought but still variety “NASPOT 12 O” is high yielding variety. When drought lasts over an extended period, however, low leaf area will eventually lead to yield reduction (Okogbenin *et al*., 2013). Drought occurrence during tuber initiation and tuber bulking, physiological processes like increasing stomatal resistance, decrease CO_2 exchange, net photosynthetic rate and eventually yield (Mukhopadhyay *et al*., 2011). The yield reduction correlates well with the findings of Heerden and Laurie (2008) who reported a reduction of 80% in yield when the cultivar Resisto was subjected to drought stress. Saqib *et al*. (2017) also stated storage root per plant decreases with increasing water stress.

Maximum biomass fresh weight per plant was obtained when variety “NASPOT 12 O” was irrigated daily than “Dilla” and “Kulfo”. As compared to daily irrigation, extending irrigation interval to twenty-one days significantly reduced biomass fresh weight by 83%, 78% and 78%; “Kulfo”, “Dilla” and “NASPOT 12 O” varieties, respectively (Table 13). This indicated that variety “Kulfo” was more sensitive to moisture stress than “Dilla” and “NASPOT 12 O” variety in terms of biomass accumulation. From the result it was observed that response to moisture stress was relatively better manifested in variety “NASPOT 12 O” and “Dilla” than “Kulfo” variety under prolonged irrigation interval. This result is related with the finding of Heerden and Laurie (2008) who stated reduction in sweetpotato biomass fresh weight at severe moisture reduction. Likewise, Saraswati *et al*.

(2004) also reported severe reduction in sweetpotato biomass under decreasing soil water regimes compared to growth under well-watered conditions in pot experiment.

Table 13. Interaction effects of sweetpotato variety and irrigation interval on tuber fresh weight and biomass fresh weight

Irrigation interval (Days)	**Varieties**		
	NASPOT 12 O	**Kulfo**	**Dilla**
Tuber fresh weight(g)			
Daily	700.00^{a}	233.33^{d}	533.33^{b}
7	366.67^{c}	133.33^{de}	200.00^{de}
14	166.67^{de}	100^{ef}	133.33^{de}
21	100^{ef}	0^{f}	100^{ef}
LSD	109.96		
CV%	28.17		
Biomass fresh weight(g)			
Daily	1266.7^{a}	600.0^{cd}	1066.7^{b}
7	766.7^{c}	400.0^{efg}	500.0d^{ef}
14	533.3^{de}	333.3^{fg}	400.0^{efg}
21	266.7^{gh}	100.0^{h}	233.3^{gh}
LSD	171.67		
CV	18.81		

Where, LSD and CV indicate least significance difference and Coefficient of variation, respectively. Means in the same column followed by the same letter are not significantly different at the 5% probability level.

4.4.2. Tuber number

The interaction effect of variety and irrigation interval was significantly ($P \leq 0.001$) affected tuber number (Appendix Table II). The maximum tuber number observed from variety “NASPOT 12 O” treated with daily irrigation and the minimum was from variety “Kulfo” treated with twenty-one days irrigation interval with no tuber obtained (Figure 1). All varieties tuber number and thickness was decreased with prolonged irrigation interval. Tuber number reduced among varieties by 100%, 57% and 54% in “Kulfo”, “Dilla” and “NASPOT 12 O” varieties, respectively, under prolonged irrigation interval (data not seen in the paper). Adaptation to moisture stress was largely observed by variety “NASPOT 12 O” than the two varieties both in tuber fresh weight and tuber number (Table 13; Figure 8).

The study also revealed that with normal soil moisture tuber root with (diameter: > 5 cm) and with twenty-one days irrigation interval increased pencil size and misshapen tuberous root up to no tuber root was obtained. Also prolonged irrigation interval decreased number of adventitious roots that would differentiate into storage roots (Daryanto *et al.*, 2016). This result is related with the finding of Ekanayake and Collins (2004), which stated reduction of sweetpotato tuberous root with water scarcity.

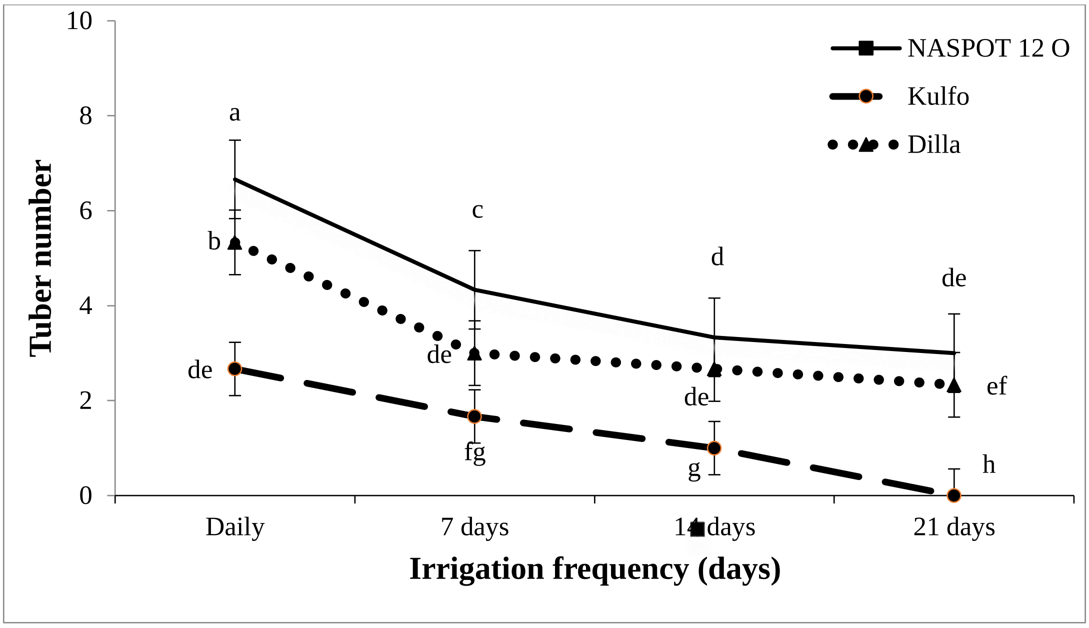

Figure 8. Interaction effects of sweetpotato variety and irrigation interval on tuber number. While, means with different letter on the figure are statistically significant at *P*-values < 0.05, LSD (0.05), = 0.77 and CV (%) = 15.77.

4.5. Correlation Analysis

4.5.1. Associations between physiological parameters and tuber fresh weight of sweetpotato varieties under different irrigation interval.

Correlation analysis indicated that, the relationship of all physiological parameters had significant ($P \leq 0.001$) strong positive correlation and leaf temperature negatively significantly ($P \leq 0.001$) correlated with tuber fresh weight (Table 14). Leaf temperature negatively significantly correlated with all morphological parameters except vine length. Vine length not significantly correlated with all physiological parameters.

Table 14. Pearson's correlation coefficient among the "physiological traits" and "tuber fresh weight" of sweetpotato varieties grown under different irrigation interval

	A	**E**	**g_s**	**IWUE**	**RLWC**	**Fv/Fm**	**LT**
BN	0.83^{***}	0.72^{***}	0.65^{***}	0.73^{***}	0.65^{***}	0.61^{***}	-0.74^{***}
LN	0.57^{***}	0.46^{**}	0.37^{*}	0.58^{***}	0.58^{***}	0.45^{**}	-0.49^{**}
LA	0.97^{***}	0.91^{***}	0.89^{***}	0.78^{***}	0.76^{***}	0.55^{***}	-0.91^{***}
IL	0.67^{***}	0.70^{***}	0.66^{***}	0.63^{***}	0.52^{**}	0.32^{ns}	-0.65^{***}
VL	0.22^{ns}	0.15^{ns}	0.07^{ns}	0.22^{ns}	0.10^{ns}	0.06^{ns}	-0.096^{ns}
RN	0.56^{***}	0.56^{***}	0.59^{***}	0.62^{***}	0.73^{***}	0.32^{ns}	-0.69^{***}
VFW	0.81^{***}	0.79^{***}	0.79^{***}	0.74^{***}	0.73^{***}	0.65	-0.84^{***}
TFW	0.86^{***}	0.86^{***}	0.89^{***}	0.72^{***}	0.66^{***}	0.48^{**}	-0.84^{***}
BFW	0.88^{***}	0.87^{***}	0.89^{***}	0.76^{***}	0.73^{***}	0.58^{***}	-0.89^{***}

Where, ns= non significance, ****=significance at* $P \leq 0.1\%$*, A= photosynthesis, E=transpiration,* g_s*= stomatal conductance, IWUE= instantaneous water use efficiency, RLWC= relative leaf water content, Fv/Fm= maximum quantum yield of photo system two, LT= leaf temperature, BN= branch number, LN= leaf number, LA= leaf area, IL= Internode length, VL= vine length, RN= root number, VFW= vine fresh weight, TFW= tuber fresh weight, BFW= biomass fresh weight.*

4.5.2. Associations between morphological parameters and tuber fresh weight of sweetpotato variety under different irrigation interval.

Correlation analysis indicated that, the relationship of all morphological parameters had significant ($P \leq 0.001$) strong positive correlation with fresh weights except vine length had insignificant negative correlation with tuber fresh weight (Table15).

Decreased leaf growth, total leaf area, leaf number, branch number, Internode length, root number and vine length were observed under the drought conditions in many plant species, such as sweetpotato, peanut and Oryza sativa. Although water saving is the important outcome of lower leaf area, it causes reduced crop yield through reduction in photosynthesis. Decrease in plant biomass consequences from the water deficit in crop plants, mainly due to low photosynthesis and plant growth and leaf senescence during the stress conditions (Seyed *et al*., 2012).

Table 15. Pearson's correlation coefficient among the "morphological traits" and "tuber fresh weight" of sweetpotato varieties grown under different irrigation interval

	BN	**LN**	**LA**	**IL**	**VL**	**RN**	**VFW**	**TFW**
LN	0.87^{***}	1						
LA	0.83^{***}	0.59^{***}	1					
IL	0.68^{***}	0.57^{***}	0.66^{***}	1				
VL	0.46^{**}	0.64^{***}	0.15^{ns}	0.35^{*}	1			
RN	0.47^{**}	0.40^{*}	0.59^{***}	0.52^{***}	-0.03^{ns}	1		
VFW	0.68^{***}	0.38^{***}	0.82^{***}	0.59^{***}	0.01^{ns}	0.53^{***}	1	
TFW	0.61^{***}	0.28^{ns}	0.84^{***}	0.61^{***}	-0.02^{ns}	0.57^{***}	0.83^{***}	1
BFW	0.67^{***}	0.34^{*}	0.87^{***}	0.63^{***}	-0.01^{ns}	0.58^{***}	0.94^{***}	0.97^{***}

Where, ns= non significance, ****=significance at* $P \leq 0.1\%$*, BN= branch number, LN= leaf number, LA= leaf area, IL= Internode length, VL= vine length, RN= root number, VFW= vine fresh weight, TFW= tuber fresh weight, BFW= biomass fresh weight.*

5. SUMMARY, CONCLUSION AND RECOMMENDATION

5.1. Summary

Sweetpotato is herbaceous dicotyledonous plant with creeping, perennial vines and adventitious roots which belongs to the family Convolvulaceae. It has large, starchy, sweet-tasting and tuberous roots and highly heterozygous cross pollinated crop in which many of the traits show continuous variation. Sweetpotato is source of energy, has nutritional value, used for more than 15 health benefits, source of vitamins, particularly suitable for food security due to its adaptability in diverse environment using low input and little attention. In Ethiopia sweetpotato is mostly cultivated in the southern, southwestern and eastern parts of the country and recognized as the third important root crop next to Enset and Potato.

Drought stress is one of the major yield limiting factors in sweetpotato production. Soil moisture stress particularly at early growth stage is a crucial factor that limits sweetpotato growth and development through affecting storage root production and yield. The most tolerant plants show inherent morphological and physiological mechanisms of drought avoidance and phenotypic flexibility, as a natural defense towards water scarceness conditions. Despite the well-established importance of sweetpotato, the limitation of information on this crop regarding morphological and physiological response and adaptation capacity of the crop to changing and more adverse climate conditions are the main problems in improving production and productivity of the crop. Therefore, this study was designed to screen sweetpotato varieties tolerant to moisture stress based on their morphological and physiological responses.

The experiment was conducted under shade house from October 2019 to March 2020, at Hawassa University College of Agriculture. The treatment was comprised of a factorial combination of three sweetpotato varieties (NASPOT 12 O, Kulfo, and Dilla) and four irrigation intervals (daily, 7 days, 14 days and 21 days) with three replication, totally 12 treatment combinations was formed using complete randomized design (CRD).

The result of this study shows that morphological parameters such as branch number, leaf number, root number, leaf area and tuber fresh weight were significantly affected by main factors and their interaction. Vine length and Vine fresh weight had significant difference on varieties and irrigation interval, while Internode length significantly differed on irrigation interval. All varieties were significantly affected by prolonged irrigation interval.

The result indicates that there were variations among varieties of sweetpotato. Variety "NASPOT 12 O" was superior in tuber, vine and biomass fresh weight, branch number, Leaf number and leaf area while, the minimum was observed from variety "Kulfo". Regarding Internode length and vine length variety "Dilla" has highest value and the minimum was recorded from variety "NASPOT 12 O".

Regarding physiological parameters like chlorophyll concentration, proline concentration, gas exchange parameters, Instantaneous water use efficiency, relative leaf water content and Maximum quantum yield of PSII (Fv/Fm) were significantly affected by interaction of the main factors. Whereas, Leaf temperature and leaf reflectance, were significantly influenced by variety and irrigation. While, stomatal number was significantly influenced only by varieties. All physiological factors except leaf temperature and proline content decreased with increasing water stress in all varieties.

5.2. Conclusion

Overall, taking all these above result into consideration we can conclude that different irrigation interval affects both morphological and physiological traits. Sweetpotato varieties have diverse mechanisms for response and adaptation to various moisture levels. The maximum branch number, leaf number and vine length were observed from variety “Dilla” and “Kulfo”, while Internode length was observed from variety “Dilla”; Whereas, the minimum was from Variety “NASPOT 12 O”. Accordingly, variety “NASPOT 12 O” produced the maximum values for fresh weights (vine, tuber and biomass) and all physiological factors. Contrarily, the lowest values were observed from variety “Kulfo” in chlorophyll concentration, leaf gas exchange parameters IWUE and RLWC. While, the minimum value of Chlorophyll florescence was observed from variety “Dilla”. The results also suggest that variety “NASPOT 12 O” had higher leaf water content and yield potential and able to survive from drought than the two varieties.

5.3. Recommendation

Based on the present finding, some recommendations are given as follows: Variety “NASPOT 12 O” responded better in tuber number, fresh weights (vine, tuber and biomass) and physiological parameters. Hence it was considered more tolerant than the two varieties.

NASPOT 12 O with seven days irrigation interval is recommended and for areas where there is severe water scarcity variety NASPOT 12 O with 14 days irrigation interval is recommended. It must be noted in mind that this experiment is done with few varieties in one season. Consequently, further research is needed for morphological and physiological responses under different varieties and water stress in open field condition before a generalized conclusion can be drawn.

6. REFERENCE

Abobatta, W.F. 2019. Drought adaptive mechanisms of plants – a review. *Adv Agr Environ Sci.* 2(1): 62−65. DOI: 10.30881/aaeoa.00022

AFA. 2011. Agriculture, Forestry and Fisheries of South Africa. Sweetpotato *(Ipomoea batatas L.*) production

Agbicodo, E., Fatokun, C., Muranaka, S., Visser, R. 2009. Breeding drought tolerant cowpea: Constraints, accomplishments, and future prospects. Euphytica, 167, 353–370.

Amare, B., F. Abay and Y. Tsehaye. 2014. Evaluation of sweet potato (Ipomea batata L.) varieties for total storage root yield in south and south east zones of Tigray, Ethiopia. Am. J. Trade Policy, 1: 74-78.

Amina, L., Ahmed A., Youcef H. and Samira S. 2014. "Effects of Water Regime on the Structure of Roots and Stems of Durum Wheat (*Triticum durum* Desf.)", *Journal of Botany*, vol. 2014, Article ID 703874, 7 pages,. https:// doi.org/ 10.1155 /2014/ 703874

Anjum, S.A., Xie, X.Y., Wang L. C., Saleem M.F., Man, C. and Lei, W. 2011. Morphological, physiological and biochemical responses of plants to drought stress.

Anoma, Ch. and Thamilini, J. K. 2016. "Roots and Tuber Crops as Functional Foods: A Review on Phytochemical Constituents and Their Potential Health Benefits", *International Journal of Food Science*, vol. 2016, Article ID 3631647, 15 pages, 2016. doi.org/10.1155/2016/3631647

Arve, L. E., Torre, S., Olsen, J. E. and Tanino K. K. 2011. Stomatal Responses to Drought Stress and Air Humidity. DOI: 10.5772/24661

Assefa, T., Teshome, A., Engida, T. and Tesfaye, T. 2007. Summary of progress on orange-fleshed sweetpotato research and development in Ethiopia. In Proceedings of the 13th ISTRC Symposium. pp. 728-731.

Austin, D.F. 1987. The taxonomy, evolution and genetic diversity of sweetpotatoes and related wild species, in: Exploration, maintenance and utilization of sweetpotato genetic resources, in: Proceedings of the First Planning Conference, Lima, Peru, International Potato Center (CIP), pp. 27–59.

Baiyeri, K., P. Apeh, G. Stevens, O. Ndukwe, S. Aba and G. Otitoju. 2015. Growth Performance and nutrient quality of three Moringa oleifera accessions grown as pot plant under varied manure rates and watering intervals. Afri. J. Biotech., 14(24): 1996 – 2004.

Basu, S., Ramegowda, V., Kumar, A., and Pereira, A. 2016. Plant adaptation to drought stress. F1000.FacultyRev-1554. doi.org/10.12688/f1000 research. 7678.1

Bates, L.S, Waldren R.P. and Teare, ID. 1973. Rapid determination of free proline for water-stress studies. Plant Soil. 39:205−207.

Belhadj, S., A. Derridj, A. Moriana, C. Gijon., P. Mevy and T. Gauquelin. 2011. Comparative analysis of stomatal characters in eight wild atlas pistachio populations (Pistacia atlantica Desf.; Anacardiaceae). Int. Res. J. Plant Sci., 2(3): 060-069

Bertolde, F., Almeida, A., Pirovani, P., et al. 2012. Physiological and biochemical responses of Theobroma cacao L. genotypes to flooding. Photosynthetica 50: 447-457.

Birhanu Lencha, Adanech Birksew and Genet Dikale, 2016. The Evaluation of Growth Performance of Sweet Potato (Ipomoea Batatas L.) Awassa Var. by Using Different Type of Vine Cuttings. Food Science and Quality Management. ISSN 2224-6088 (Paper) ISSN 2225-0557 (Online). Vol.54, 2016.

Black, C. 1965. Methods of soil analysis. Part I, American Society of Agronomy. Madison, Wisconsin, USA. 1572.

Blonquist, J.M., Norman, J.M., and Bugbee, B. 2009. Automated measurement of canopy stomatal conductance based on infrared temperature. Agric For Meteorol 149: 2183-2197.

Blum, A. 2005. Drought resistance, water-use efficiency, and yield potential are they compatible, dissonant, or mutually exclusive? Australian J. Agric. Res. 56:1159-1168.

Bosabalidis, A. and G. Kofidis. 2002. Comparative effects of drought stress on leaf anatomy of two olive cultivars. Plant Science. 163: 375-379.

Boutraa, T., Akhkha, A., Al-Shoaibi, A. A. and A. Alhejeli, M. 2010. Effect of water stress on growth and water use efficiency of some wheat cultivars (grown in Saudi Arabia., Journal of Taibah university for science, 3:1, 39-48. DOI: 10.1016/S16583655 (12)60019-3

Bray, E.A. 1997. Plant responses to water deficit. Trends plant science. 2:48-54

Bray, R.H., Kurtz, L.T. 1945. Determination of total organic and available forms of phosphorus In Soils. Soil Science. 59:35-45.

Breda, N.J.J. 2003. Ground-based measurements of leaf area index: A review of methods, instruments and current controversies. Journal of Experimental Botany, 54, 2403-2417. http://dx.doi.org/10.1093/jxb/erg263.

Britannica, T. Editors of Encyclopaedia (Invalid Date). *Sweet potato*. *Encyclopedia Britannica*. https://www.britannica.com/plant/sweet-potato. Accessed 2021

Campos, P.S., J.C. Ramalho, J.A. Lauriano, M.J. Silva and M. do Ceo Matos. 1999. Effects of drought on photosynthetic performance and water relations of four vigna genotypes. Photosynthetica. 36:79-87.

Charles O. Ochieng. 2014. Morphological, physiological and molecular characterization of drought tolerance in cassava (Manihot esculenta Crantz). DISS.ETH NO.21699

Chaves, M. and C. Pinheiro. 2009. Photosynthesis under drought and salt stress: regulation Mechanisms from whole plant to cell. Annals of Bot., 103(4):551-560.

Chaves, M. M., Maroco, J. P., and Pereira, J. S. 2003. Understanding plant responses to drought: from genes to the whole plant. *Funct. Plant Biol.* 30, 239–264. doi: 10.1071/FP02076/1445-4408/03/030239.

Collins, W. 1998. Department of Horticultural Science, Box 7609, North Carolina State University, Raleigh, North Carolina 27695-7609

Cornic, G. 2000. Drought stress inhibits photosynthesis by decreasing stomatal aperture not by affecting ATP synthesis. Trends in Plant Science. 5:187-188.

CSA. 2018. Ethiopia Agricultural Sample Survey: Area and production of major crops (Private Peasant Holdings, Meher Season). Central Statistical Agency (CSA), Federal Democratic Republic of Ethiopia, Addis Ababa, Ethiopia.

Daryanto, S., Wang, L., and Jacinthe, P. A. 2016. Drought effects on root and tuber production: A meta-analysis. Agricultural Water Management, 176, 122-131. http://dx.doi.org/10.1016/j.agwat.2016.05.019

Dillen, S., N. Marron, B. Koch, and R. Ceulemans. 2008. Genetic variation of stomatal traits and carbon isotope discrimination in two hybrid poplar families (Populus deltoids 'S9-2' x P. nigra 'Ghoy' and P. deltoides 'S9-2' x P. trichocarpa 'V24').Ann Bot.102:399–407.

Doupis, G., Bertaki, M., Psarras, G., Kasapakis, I. and Chartzoulakis, K. 2013. Water relations, physiological behavior and antioxidant defence mechanism of olive plants subjected to different irrigation regimes. Sci Hortic 153: 150-156.

Duvernay, W.H., Ms. Chinn and Yencho G.C. 2013. Hydrolysis and fermentation of sweet potatoes for production of fermentable sugars and ethanol. Ind Crops Prod 42: 527-537.

Ekanayake, I.J. and Collins, W. 2004. Effect of irrigation on sweetpotato root carbohydrates and nitrogenous compounds. Food, Agriculture & Environment, 2, 243-248.

Esan, V., Omilani, O., Adejumo, S., Adeyemo, T. O. and Akinbode O. A. 2018. Screening of sweetpotato ((Ipomea batatas [L.] Lam.) cultivars for drought tolerance. IJEAB, Vol-3, Issue-3, ISSN: 2456-1878. http://dx.doi.org/10.22161/ijeab/3.3.3

Fabio, T.D., Igor, R.A., Diego, F.V.C., Mariane, G.F., Luiz, E.D., Angelica, R., Jose C.Z. and Derly J.H.S. 2018. Morpho-physiological characteristics by sweetpotato cultivars as function of irrigation depth. An. Acad. Bras. Cienc. Vol. 90 (4).

FAO. 2016. Food and Agricultural Organization Statistics, Rome, Italy.

FAO. 2018. Food and Agriculture organization of United Nations: FAO’S Work on climate change.

Farooq, M., A. Wahid, N. Kobayashi, D. Fujita and S.M.A. Basra. 2009. Plant drought stress: effects, mechanisms and management. Agron. Sustain. Dev., 29: 185-212.

Farshadfar, E. and Sutka, J. 2002. Screening drought tolerance criteria in maize. Acta Agron Hungarica 50: 411-416.

Fernandez, G.C.J. 1992. Effective selection criteria for assessing plant stress tolerance. Proceedings of the International Symposium on Adaptation of Vegetables and other Food Crops in Temperature and Water Stress. Shanhua,Taiwan.

Flexas, J., Bota, J., Cifre, J., Escalona, J.M., Galmés, J., Gulias, J., Lefi, E.K., Martinez-Canellas, S.F., Moreno, M.T. and Ribas-Carbó, M. 2004. Understanding down-regulation of photosynthesis under water stress:future prospects and searching for physiological tools for irrigation management. Ann. Appl. Biol. 144: 273-283.

Flexas, J., Medrano, H. (2002). Drought-inhibition of photosynthesis in C-3 plants: Stomatal and non stomatal limitation revisited. Ann. Bot. 89: 183-1890.

Gailing, O., R. Langenfeld-Heyser, A. Polle and R. Finkeldey. 2008. Quantitative trait loci Affecting stomatal density and growth in a Quercus robur progeny: implications for the adaptation to changing environments. Glob. Change Biol 14:1934–46.

Gajanayake, B., Reddy, K.R., Shankle, M.W. and Arancibia, R.A. 2014. Growth, developmental, and physiological responses of two sweet potato (Ipomoea batatas L. [Lam]) cultivars to early season soil moisture deficit. Sci Horti. 168:218 - 228.

Ghodsi, M., M. Nuzeri and A. Zarea-Fizabady. 1998. The reaction of new cultivars and Alite lines on spring wheat into drought stress, Collection of abstract articles of 5 the Iranian agronomy and plant breeding conference, Karaj, Iran. 252p.

Gomes, F. and Carr, M.K.V. 2001. Effects of water availability and vine harvesting frequency on the productivity of sweetpotato in Southern Mozambique. I. Storage root and vine yields. Exp Agric. 37:523 - 537.

Gomes, F., Carr, M.K.V. and Squire, G.R. 2005. Effects of water availability and vine harvesting frequency on the productivity of sweetpotato in Southern Mozambique. IV. Radiation interception, dry matter production and partitioning. Exp Agric. 41:93 - 108.

Gurmu, F. and Mekonen S. 2017. Registration of a Newly Released Sweet Potato Variety ‘‘Hawassa-09’’ for Production in Ethiopia. Agrotechnology 6: 160. doi: 10.4172/2168-9881.1000160

Gurmu, F. and Mekonen S. 2019. Evaluation of root yield performance of newly bred orange-fleshed sweet potato genotypes in Ethiopia. Journal of Agricultural and Crop Research Vol. 7(1), pp. 9-17, doi: 10.33495/jacr_v7i1.18.154

Gurmu, F. and Tesfaye, T. 2016. Sweetpotato production and post-harvest handling. A manual prepared for agricultural experts (unpublished).

Gurmu, F., Hussein, S. and Laing, M. 2015. Diagnostic assessment of sweetpotato production in Ethiopia: Constraints, post-harvest handling and farmers' preferences. Research on Crops, 16(1), 104-115.

Haimeirong Kubota, F. 2003. The effects of drought stress and leaf ageing on leaf photosynthesis and electron transport in photosystem 2 in sweetpotato (Ipomoea batatas Lam.) cultivars. Photosynthetica. 41:253-258.

Halder K.P. and Burrage S.W. 2003. Drought Stress Effects On Water Relations Of Rice Grown In Nutrient Film Technique. Pakistan journal of Biological sciences, 6:441-444. DOI: 10.3923/pjbs.2003.441.444

Heerden, V., P. D. R., and Laurie, R. 2008. Effects of prolonged restriction in water supply on photosynthesis shoot development and storage root yield in sweet potato. PhysiologiaPlantarum.134:99-109.

Henderson, S.A. and Fukai, S. 1998. The use of seedling leaf death score for evaluation of drought resistance of rice. Field Crops Research 55(1-2): 129-139.

Herbinger, K., Tausz, M., Wonisch, A., Soja, G., Sorger, A. and Grill, D. 2002. Complex interactive effects of drought and ozone stress on the antioxidant defense systems of two wheat cultivars. Plant Physiol. Biochem. 40: 691–696.

Hetherington, A. and Woodwar, F. 2003. The role of stomata in sensing and driving Environmental change. Natur. 424: 901-908.

Hu, X.J.F.Y. Yu, J.B Lui and J.Wan, 2009. Effect of drought stress on soluble sugar content in needles of pinus massoniana seedlings from different provenances. J. Nanjing For. Univ.

Huaman, Z. 1987. Current status on maintenance of sweetpotato genetic resources at CIP: Exploration, maintenance and utilization of sweetpotato genetic resources. First Sweetpotato Planning Conference. CIP, Lima, Peru. p. 101-120.

Hussain, M., Malik, M.A., Farooq, M., Ashraf, M.Y. and Cheema M.A. 2008. Improving drought tolerance by exogenous application of glycinebetaine and salicylic acid in sunflower. J. Agron. Crop Sci., 194: 193-199.

Ierna, A. and Mauromicale G. 2012. Tuber yield and irrigation water productivity in early potatoes as affected by irrigation regime. Agric Water Manag 115: 276-284.

Igamberdiev, A. U., Mikkelsen, T. N., Ambus, P., Bauwe, H., Lea, P. J. and Gardestrom, P. 2004. Photorespiration contributes to stomatal regulation and carbon isotope fractionation: A study with barley, potato and Arabidopsis plants deficient in glycine decarboxylase. Photosynthesis Research 81(2):139-152.

IturbeOrmaetxe, I., Escuredo, P.R., Arrese-Igor, C. and Becana M.1998. Oxidative damage in pea plants exposed to water deficit or paraquat. Plant Physiol. 116: 173–181.

Jackson, R. B., Sperry, J. S., and Dawson, T. E. 2000. Root water uptake and transport: using physiological processes in global predictions. *Trends Plant Sci.* 5,482–488. doi:10. 1016/S 1360-1385 (00) 01766-0

Jaleel, Ca., Manivannan, P., Wahid, A., Muhammad, F., Hameed J., Ramamurthy S. and Rajaram PV. 2009. Drought stress in plants: A review on morphological characteristics and pigments composition. Int J Agric Biol 11: 100-105.

Jefferie S. R. A.1992. Cultivar responses to water stress in potato: effects of shoot and roots. New Phytol. 123, 491-498

Jerry L.H. and Christian D. 2019. Water use efficiency: Advances and challenges in a changing climate. Front. Plant sci., 19.

Ji, Z.B., J.X. Wang, J.W. Li, S. Xue and M.L. Zhang. 2009. Dynamic changes of soluble sugar in the seedlings of Robinia pseudoacacia under drought stress and rewatering in different seasons. Acta Bot. Boreali-Occidentalia Sin.,

Jones, H.G. 2014. Plants and Microclimate: A Quantitative Approach to Environmental Plant Physiology. Cambridge: Cambridge University Press.

Jones, Jr. JB. 2002. Agronomic handbook: Management of crops, soils and their fertility: CRC press:

Kamara, A., Menkir, A., Badu-Apraku, B. and Ibikunle, O. 2003. The influence of drought stress on growth, yield and yield components of selected maize genotypes. The Journal of Agricultural Science, 141(1):43-50.

Kim, S.H., Song, W.K., Kim, Y.H., Kwon, S.Y., Lee, H.S., I.C. Lee and Kwak, S.S. 2009. Characterization of full-length enriched expressed sequence tags of dehydration-treated white fibrous roots of sweet potato. BMB Rep. 42:271-276.

Kirnak, H., Kaya, C., I. Tas and Higgs, D. 2001. The influence of water deficit on vegetative growth, physiology, fruit yield and quality in eggplants. *Bulgarian Journal Plant Physiology* **27(3-4),** 34-46.

Kulkarni M. and Phalke S. 2009. Evaluating variability of root size system and its constitutive traits in hot pepper (Capsicum annum L.) under water stress. Sci Hortic 120:159-166.

Laurie, R., Plooy, Ph.Ch., Laurie,Du. S. M., J. F. Finnie and J. Van Staden. 2015. Yield of Drought-Stressed Sweet Potato in Relation to Canopy Cover, Stem Length and Stomatal Conductance. Journal of Agricultural Science Vol. 7, No. 1. DOI:10.5539/jas.v7n1p201.

Lawlor, W. and Tezara. 2009. Musings about the effects of environment on photosynthesis. Ann Bota., 103(4):543-5549.

Lebot, V. 2009. Sweetpotato. In: Bradshaw, J.E., editor, Root and tuber crops: Handbook of plant breeding. Springer Sciences and Business Media, New York, NY 10013, USA. p. 97-125.

Lee, W., Chen, I., Chang, C. and Yang S. 2012. Bioethanol production from sweet potato by co-immobilization of saccharolytic molds and Saccharomyces cerevisiae. Renew Energy. 39: 216-222.

Lewthwaite, S. L. and Triggs, C. M. 2012. Sweetpotato cultivar response to prolonged drought. Agronomy New Zealand, 42, 1-10.

Lewthwaite, S.L. 1998. Commercial sweet potato production in New Zealand: foundations for the future. pp. 33-50.

Lewthwaite, S.L. and Triggs, C.M. 2012. Sweet potato cultivar response to prolonged drought. Agronomy New Zealand 42

Lichtenthaler, H.K. 1987. Chlorophylls and carotenoids: Pigments of photosynthetic biomembranes. Methods Enzymol. 148: 350-380.

Lichtenthaler, H.K. and C. Buschmann, 2001.Chlorophylls and Carotenoids - Extraction, Isolation and Purification. *Current Protocols in Food Analytical Chemistry (CPFA)*, (Supplement 1), Unit F4.2.1-F4.2.6

Liu, F. L., Jensen, C.R., Shahanzari, A., Andersen, M. N. and Jacobsen, S.E. 2005. ABA regulated stomatal control and photosynthetic water use efficiency of potato (*Solanum tuberosum* L.) during progressive soil drying. *Plant Sci.* 168, 831–836.DOI:10.1016/j.plantsci.2004.10.016

Loggini, B., Scartazza, A., Brugnoli, E. and Navari-Izzo, F. 1999. Antioxidant defense system, pigment composition, and photosynthetic efficiency in two wheat cultivars subjected to drought. Plant Physiol. 119:1091–1099.

Louise H. 2019. Types of Sweet Potatoes (With Images) and Why You Should Eat Each.

Ludlow, M. and Muchow, R. A. 1990. Critical evaluation of traits for improving crop yields in water limited environments. In: Advances in agronomy. Elsevier, 43:107-153.

Ludlow, M. M. 1980. Physiological adaptations to water stress: Adaptive significance of stomatal responses to water stress. In: N. C. Turner. and P. J. Kramer (Eds.), Adaptation of Plants to Water and High Temperature Stress, John Wiley and Sons, New York, Pp. 123-138

Machado, Ec., Schmidt, Pt., Lazaro, C. and Vasconcelos, R. 2005. Respostas da fotossíntese de três espécies de citros a fatores ambientais. Pesqui Agropecu Bras 40: 1161-1170.

Markos D. and Loha G. 2016. Sweet Potato Agronomy Research in Ethiopia: Summary of Past Findings and Future Research Directions. Agriculture and Food Sciences Research, 3(1):1-11

Maria Gomez-del-campo, Constantino Ruiz, and Jose Ramon Lissarrague. 2002. Effect of water stress on leaf area development, photosynthesis and productivity in chardonnay and Airen grapevines. Am. J. Vatic. 53:2

Maxwell, K. and Johnson, G. N. 2000. Chlorophyll fluorescence-a practical guide. J Exp Bot. 51:659–668.

Mckay, J. K., Richards J. and Mitchell- Olds T. 2003. Genetics of drought adaptation in Arabidopsis thaliana: pleiotropy contributes to genetic correlations among ecological treats. Mol. Ecol. 12:1137-1151.

Medina, S., Vicente, R., Nieto-Taladriz, M. T., Aparicio, N., Chairi, F., Vergara-Diaz, O., and Araus J. L. 2019. The Plant-Transpiration Response to Vapor Pressure Deficit (VPD) in Durum Wheat Is Associated With Differential Yield Performance and Specific Expression of Genes Involved in Primary Metabolism and Water Transport. *Front. Plant Sci*. 9:1994. doi: 10.3389/fpls.2018.01994

Mishra, K.B., Iannacone, R., Petrozza, A., Mishra, A., Armentano, N., La V. G., Trtílek, M., Cellini, F. and Nedbal, L. 2012. Engineered drought tolerance in tomato plants is reflected in chlorophyll fluorescence emission. Plant Sci., 182, 79-86, DOI:10.1016/j.plantsci.2011.03.022

Mitchell, J. H., Siamhan, D., Wamala M. H., Risimeri J. B., Chinyamakobvu E., Henderson S. A. and Fukai S. 1998. The use of seedling leaf death score for evaluation of drought resistance of rice. Field Crops Research 55, 129–139. DOI: 10.1016/S0378-4290(97)00074-9

Mitra J. 2001. Genetics and Genetic Improvement of Drought Resistance in Crop Plants. Curr Sci. 80:758-762.

Mukhopadhyay, S.K., Chattopadhyay, A., Chakraborty, I. and Bhattacharya, I. 2011. Crops that feed the world 5: Sweetpotato. Sweetpotatoes for income and food security. Food Secur., 3:283-305. http://dx.doi.org/10.1007/s12571-011-0134-3

Muluneh Bekele Etana, Mekonnen Tolasa Gonfa and Chala Obsa Duresa. 2019. Production Constraints of Sweet Potato (Ipomoea batatas L.). International Journal of Agriculture & Agribusiness

Mutava, R.N., Prince. S.J.K., Syed, N.H., Song, L., Valliyodan, B., Chen, W. and Nguyen, H.T. 2015. Understanding abiotic stress tolerance mechanisms in soybean: A comparative evaluation of soybean response to drought and flooding stress. Plant Physiol Biochem86: 109–120

Mwanga, R..M., Kyalo, G., Ssemakula, G. N., Niringiye, C., Yada, B., Otema, M. A., Namakula, J., Alajo, A., Kigozi, B., Makumbi, R..M., Ball, A., Grüneberg, W. J., Low, J. W., & Yencho, G. 2016. 'NASPOT 12 O' and 'NASPOT 13 O' Sweetpotato, ***HortScience horts***, ***51***(3), 291-295.Retrieved Feb 6, 2021, from https://journals.ashs.org/hortsci/view/ journals /hortsci/51/3/article-p291.xml

Najla, S., Sanoubar, R. and Murshed, R. 2012. Morphological and biochemical changes in two parsley varieties upon water stress. Physiol Mol Biol Plant. 18:133–139.

Nedunchezhiyan, M., Byju, G., and Ray, R. C. 2012. Effect of Tillage, Irrigation, and Nutrient Levels on Growth and Yield of Sweet Potato in Rice Fallow. International Scholarly Research Network. ISRN Agronomy, Article ID 291285, 13

NMA (National Metrology Agency, Southern Nation Nationality and peoples regional state Metrology center, Hawassa branch). 2019. Annual Metrology data report, Hawassa, Ethiopia.

Nonami, H. 1998. Plant water relations and control of cell elongation at low water potentials. J. Plant Res., 111:373-382.

Nozipho, M. M., Albert, T. M. and Tafadzwanashe, M. 2015. Sweet potato (Ipomoea batatas L.) as a drought tolerant and food security crop. S. Afr. j. sci. vol.111 n.11-12. DOI.org/10.17159/sajs.2015/20140252

Oggema, J. N., M. G. Kinyua, J.P. Ouma and J.O. Owuoche. 2007. Agronomic performance of locally adapted sweet potato (Ipomoea batatas (L.) Lam.) Cultivars derived from tissue culture regenerated plants. Afr. J. Biotechnol., 6: 1418-1425.

Okogbenin, E., Setter, T.L., Ferguson, M., Mutegi, R., Ceballos, H., Olasanmi, B. and Fregene, M. 2013. Phenotypic approaches to drought in cassava: review. Frontiers in physiology 4, 93.

Ozias, A. P. and Jarret, R.L. 2013. Nuclear DNA content and ploidy levels in the genus *Ipomoea*. JASHS 119(1): 110-115.

Pirasteh-Anosheh, H., Saed-Moucheshi, A., Pakniyat, H. and Pessarakli, M. 2016. Stomatal responses to drought stress. Water Stress and Crop Plants, 24–40. doi:10.1002/9781119054450.ch3

Placide Rukundo, Hirut Getinet Betaw, Stephan Ngailo and Fekadu Balcha. 2014. Assessment of drought stress tolerance in root and tuber crops. Rukundo et al.215

Placide, R., Shimelis, H., Laing, M. and Gahakwa, D. 2013. Physiological mechanisms and conventional breeding of sweet potato *(Ipomoea batatas* (L) Lam) to drought-tolerance. Afr J Agric Res.;8:1837-1846.

Poonam, R. B., Neha, H., Harpreet, K., Amandeep, R., Shagun, B., Vandana G., Anket, Sh., Puja, O., Ashwani K. Th., Geetika, S. and Saroj, A. 2016. Sugar signaling in plants.

Qadir, G., Ishtiaq and Ali, L. 1999. Effect of earthing at different stages of growth on the yield of different potato cultivars under the soil and climatic conditions of Peshawar (pakistan). Sarhad j. agric., 15:423-425.

Ramirez, G.P. 1992. Cultivation harvesting and storage of sweet potato products. Seed, 6:6.

Remison, S.U. 1997. Basic Principle of Crop Physiology. Sadoh Press (Nig.), Benin City, pp. 16

Rennenberg, H., Loreto, F., Polle, A., Brilli, F., Fares, S., Beniwal, R. S. and Gessler, A. 2006. Physiological responses of forest trees to heat and drought. PlantBiol 8:556–571.

Ribeiro, Ac., Guimarães Ptg and Alvarez Vh. 1999. Recomendações para o uso de corretivos e fertilizantes em Minas Gerais, 5th ed., Soc Bras Ciênc Solo, Viçosa.

Rodriguez-Delfín, A., Posadas, A., Leon-Valarde, C., Mares, V. and Quiroz, R. 2012. Effect of salt and water stress on the proline and total chlorophyll content and nutrients uptake on two sweet potato cultivars grown on soilless culture. Acta Hortic. 947:55□62.

Rolando, Y. W. 2017. Top Sweet Potato Growing Countries. Retrieved from https://www.worldatlas.com/articles/top-sweet-potato-growing-countries.html

Roro, A. G., and Tesfaye, M. 2019. Morpho-physiological and Yield Responses of Sweet Potato (Ipomoea batatas (L.) Lam.) Genotypes to Frequency of Irrigation under Greenhouse Condition. *International Journal of Plant & Soil Science*, *29*(5), 1-17. https://DOI.org/10.9734/ijpss/2019/v29i530155

Rosielle, A. A. and Hamblin, J. 1981. Theoretical Aspects of Selection for Yield in Stress and Non-Stress Environment. Crop Sci 21: 943–946.

Saeid, H., Zeinolabedin, TS., Seyed A. M. MS., Ali MB. and Silvana N. 2016. Effect of water stress and light intensity on chlorophyll florescence parameters and pigments of Aloe vera L. plant physiology and biochemistry 106: 141-148.

Salisbury, E.J. 1927. on the causes and ecological significance of stomatal frequency with special reference to the woodland flora. Philosophical Transactions of the Royal Society of London B Biological Sciences, vol. 216, p. 1-65.

Sani, A., Abdullah, W.O., Juhana, T., and Adel, M. 2014. Extraction, characterization and total phenolic content of local (malaysian) green sweetpotato (ipomoea batatas) leaves.

Saqib, M., Khalid, M.F., Hussain, S., Anjum, M.A. 2017. Effect of water stress and planting system on growth, yield and quality of sweet potato. Acta Sci. Pol. Hortorum Cultus, 16(6), 201–210. DOI: 10.24326/asphc.2017.6.18

Saraswati P. 2007. Physiological and growth responses of selected sweet potato (*Ipomoea batatas* (L.) Lam.) Cultivars to water stress. James Cook University;

Saraswati, P., Johnston, M., Coventry, R. and Holtum, J. 2004. Identification of drought tolerant sweet potato (Ipomoea batatas (L.) Lam.) cultivars. New direction for adverse planet: Proceedings of the 4th International Crop Science Congress, 26, Brisbane, Australia.

Saraswati, P., Soplanit, A., Syahputra, A. T., Kossay, L., Muid, N., Ginting, E., and Lyons, G. 2013. Yield trial and sensory evaluation of sweetpotato cultivars in Highland Papua and West Papua Indonesia. Journal of Tropical Agriculture, 51, 74-83.

SAS Institute, 2018. SAS STAT 9.3 user's guide, vol. 5. SAS Institute, Cary, NC.

Scott, P. 2000. Resurrection plants and the secrets of eternal leaf. Ann. Bot. 85:159-166.

Sermons, S. M., Seversike, T. M., Sinclair, T. R. and Rufty T. W. 2012. Temperature influences the ability of tall fescue to control transpiration in response to atmospheric vapour pressure deficit. Funct Plant Biol 39: 979-986.

Seyed Y. S. Lisar, Rouhollah M., Mosharraf, M. Hossain and Ismail M. M. Rahman. 2012. Water Stress in Plants: Causes, Effects and Responses. In book: Water Stress, Chapter: 1, pp.1–14. DOI: 10.5772/39363

Shabala, S.N., Shabala, S. I., Martynenko, A. I., Babourina, O., Newman, I. A. 1998. Salinity effect on bioelectric activity, growth, Na+ accumulationand chlorophyll fluorescence of maize leaves: a comparative surveyand prospects for screening. Aust. J. Plant Physiol. 25: 609-616.

Shahenshah and Akihiro Isoda. 2010. Effects of water stress on leaf temperature and chlorophyll florescence parameters in cotton and peanut. Plant production science, 13:3, 269-278, DOI: 10.1626/pps. 13.269

Shavrukov, Y., Kurishbayev, A., Jatayev, S., Shvidchenko, V., Zotova, L., Koekemoer, F., de Groot, S., Soole, K., and Langridge, P. 2017. Early Flowering as a Drought Escape Mechanism in Plants: How Can It Aid Wheat Production?. *Frontiers in plant science*, *8*, 1950. https://doi.org/10.3389/fpls.2017.01950

Singh, S. k. and Reddy, Kr. 2011. Regulation of photosynthesis, fluorescence, stomatal conductance and water-use efficiency of cowpea (Vigna unguiculata [L.] Walp.) Under drought. J Photochem Photobiol B Biol. 105: 40-50.

Smirnoff N. 1995. Antioxidant systems and plant response to the environment. In: Smirnoff V (Ed.), Environment and Plant Metabolism: Flexibility and Acclimation, BIOS Scientific Publishers, Oxford, UK

Szabados, L. and Savoure, A. 2009. Proline: a multifunctional amino acid. Trends Plant Sci., 15: 89-97

Taiz L, Zeiger E (2002) *Plant Physiology*, 3rd Edn. Sinauer Associates, Inc. Sunderland, USA. 647 pp.

Tadesse, T., Haque, I. and Aduayi E. 1991.Soil, plant, water, fertilizer, animal manure and compost analysis manual;

Testi, L., Goldhamer Da., Iniesta, F. and Salinas M. 2008. Crop water stress index is a sensitive water stress indicator in pistachio trees. Irrig Sci. 26: 395-405.

Thomas N. Buckley. 2017. Modeling stomatal conductance. American Society of Plant Biologists

Toorchi, M., Shashidhar, H. E., Hittalmani, S. and Gireesha, T. M. 2002. Rice root morphology under contrasting moisture regimes and contribution of molecular marker heterozygosity. Euphytica. 126: 251–257.

Topp, G.C. 1993. Soil water content. In M.R. Carter (ed.). Soil sampling and methods of analysis. Lewis Publishers, London.

Torres-Ruiz, J.M., Diaz-Espejo, A., Morales-Sillero, A., Martín-Palomo, M.J., Mayr, S., Beikircher, B. and Fernandez J.E. 2013. Shoot hydraulic characteristics, plant water status and stomatal response in olive trees under different soil water conditions. Plant Soil373: 77–87

Torre, R., T. Maliro, W. Lorito. 2003. Determination of stomata morphology in model plants under different water stress condition. *J. Sci*., 5(1): 243- 248.

Turner, N. C. 1981. Techniques and experimental approaches for the measurement of plant water status. Plant and Soil. 58(1- 3):339-366.

Walkley, A. and Black, I.A. 1934. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. Soil Science. 37 (1):29-38.

Wei, Z., Du, T., Li, X., Fang, L. and Liu, F. 2018. Simulation of Stomatal Conductance and Water Use Efficiency of Tomato Leaves Exposed to Different Irrigation Regimes and Air CO_2 Concentrations by a Modified "Ball-Berry" Model. *Front. Plant Sci*. 9:445. doi: 10.3389/fpls.2018.00445

Williams, P.H. and Araujo, Mb. 2002. Apples, oranges, and probabilities: Integrating multiple factors intobiodiversity conservation with consistency. Environ Model Assess 7: 139-151.

Willmer, C.; Fricker, M. 1996. Stomata. 2nd Ed, Chapman and Hall, London, UK. 375 pp.

Woolfe J. A. 1992. Sweetpotato: an untapped food resource. Cambridge University Press, Cambridge, Great Britain.

Xu, S.M., L.X Lui, K.C. Woo and D.L. Wang. 2007. Changes in photosynthesis, xanthophylls cycle and sugar accumulation in to North Australia tropical species different in leaf angles. Photosynthetica, 45: 348-354.

Xuejuan Chen, Xingguo Mo, Shi Hu and Suxia Liu. 2018. Relationship between fluorescence yield and photochemical yield under water stress and intermediate light conditions. J Exp Bot. 2019 Jan 1; 70(1):301-313.

Yahaya, S. U., A. M. Saad, S. G. Mohammed, and S. O. Afuafe. 2015. Growth and Yield Components of Sweet Potato (Ipomoea batatas L.) and their Relationships with Root Yield. A J EA, 9(5): 1-7. DOI: 10.9734/AJEA/2015/20078

Yooyongwech, S., Samphumphuang, Th., Theerawitaya, C. and Cha-um, S. 2014. Physio-morphological responses of sweet potato [Ipomoea batatas (L.) Lam.] Genotypes to water-deficit stress**.** POJ 7(5): 361-368.

Yooyongwech, S., Samphumphung, Th., Tisaram, R., Theerawitaya, C. and Cha-um, S. 2017. Physiological, Morphological Changes and Storage Root Yield of Sweetpotato [Ipomoea batatas (L.) Lam.] under PEG-Induced Water Stress . Not Bot Horti Agrobo, 45(1):164-171. DOI: 10. 15835/nbha4511065.

Yooyongwech, S., Theerawitaya C., Thapanee, S. and Cha-um, S. 2013. Water-deficit tolerant identification in sweet potato genotypes (Ipomoea batatas (L.) Lam.) in vegetative developmental stage using multivariate physiological indices. Scientia Horticulturae 162 (2013) 242–251.

Zhang, R., Li, J., Guo S.R. et al. 2009. Effects of exogenous putrescine on gas exchange characteristics and chlorophyll fluorescence of NaCl-stressed cucumber seedlings. – Photosynth. Res. 100: 155-162.

7. APPENDICES

Appendix Table I. Analyses of variance for branch number, root number, leaf number, leaf area (cm^2), internode length (cm) and vine length (cm) of sweetpotato varieties under different irrigation interval

		Parameters					
Source Variation	DF	Branch number	Root number	Leaf Number	Leaf Area (cm^2)	Internode length (cm)	Vine Length (cm)
Variety(V)	2	5.55***	31.86***	7874.4***	1253682***	0.38528^{ns}	1877.58***
Irrigation(I)	3	181.39***	40.10***	28893.1***	10248160.08***	2.07287***	317.06*
V X I	6	11.95***	11.82***	6159.5***	190693.03*	0.24454^{ns}	100.95^{ns}
Error	22	0.428	1.05	541.8	62258.3	0.1471	79.57
CV		8.12	13.47	25.57	21.79	23.21	27.24

*Where, ns, * and *** indicates non-significant difference at P≤ 5%, significant difference at P≤ 5%,and P≤ 0.1% probability levels, respectively. df = degree of freedom, CV= coefficient of variance, V *I= interaction among varieties and water stress(irrigation frequency).*

Appendix Table II. Analysis of variance for chlorophyll a (chla), chlorophyll b (chlb), total chlorophyll (TC) concentration of sweetpotato varieties under different irrigation interval

		Parameters		
Source Variation	DF	Chla	Chlb	Chl(TC)
Variety	2	170.7***	114.51**	543.4***
Irrigation	3	5030.93***	1947.15***	13212***
V X I	6	53.91***	72.09**	143.5***
Error	22	2.63	13.51	13.5
CV		1.07	3.15	1.37

*Where, ns, ** and *** indicates non-significant difference at P≤ 5%, significant difference at P≤ 1% and P≤ 0.1% probability levels, respectively. df = degree of freedom, CV= coefficient of variance, V *I= interaction among varieties and water stress(irrigation frequency).*

Appendix Table IIIII. Analysis of variance for maximum quantum yield (Fv/Fm), proline content and stomata number of *sweetpotato varieties* under different irrigation interval

Source of Variation	DF	Parameters		
		Fv/Fm	Proline content	Stomata number
Variety	2	0.01785***	0.22926***	6.58***
Irrigation	3	0.11237***	0.17746***	0.48ns
V X I	6	0.01033***	0.06154***	0.06ns
Error	22	0.00141	0.00997	0.26
CV		5.03	28.60	4.23

*Where, ns, * and*** indicates non-significant difference at P≤ 5%, significant difference at P≤ 0.05% and significant difference at P≤ 0.1% probability levels, respectively. df = degree of freedom, CV= coefficient of variance, V *I= interaction among varieties and water stress(irrigation frequency).*

Appendix Table IIV. Analysis of variance for photosynthetic rate (A), transpiration rate (E), stomatal conductance (g_s), instantaneous water use efficiency (IWUE) and relative leaf water content (RLWC) of *sweetpotato varieties* under different irrigation interval.

Source of Variation	DF	Parameters				
		A	E	g_s	IWUE	RLWC%
Variety	2	15.938***	1.7996**	0.00134***	0.08^{ns}	170.14***
Irrigation	3	351.024***	18.1836***	0.009025***	11.04***	640.91***
V X I	6	11.523***	1.1354**	0.000981***	0.35**	83.199***
Error	22	0.734	0.2518	0.00008611	0.0637	8.145
CV		15.60	18.28	20.78	15.71	5.09

*Where, ns, ** and *** indicates non-significant difference at P≤ 5%, significant difference at P≤1% and P≤ 0.1% probability levels, respectively. df = degree of freedom, CV= coefficient of variance, V *I= interaction among varieties and water stress(irrigation frequency).*

Appendix Table V. Analysis of variance for leaf temperature (^oc), vine fresh weight (g), tuber fresh weight (g), biomass fresh weight and tuber number of sweetpotato varieties under different irrigation interval

		Parameters				
Source Variation	DF	Leaf temperature (^oc)	Vine fresh weight (g)	Tuber fresh Weight (g)	Biomass fresh weight (g)	Tuber number
Variety	2	11.20	53333^{***}	141944^{***}	368611^{***}	28^{***}
Irrigation	3	53.78	191389^{***}	309167^{***}	964074^{***}	16.51^{***}
V X I	6	0.91	4444ns	27500^{***}	48241^{**}	0.51^{***}
Error	22	0.77	5379	4217	10278	0.21
CV			23.79	28.17	18.81	15.35

*Where, ns, * and *** indicates non-significant difference at P≤ 5%, significant difference at P≤ 5% and P≤ 0.1% probability levels, respectively. df = degree of freedom, CV= coefficient of variance, V *I= interaction among varieties and water stress(irrigation frequency).*

Figure 9. Sweetpotato varieties under all treatments at planting and growing stage

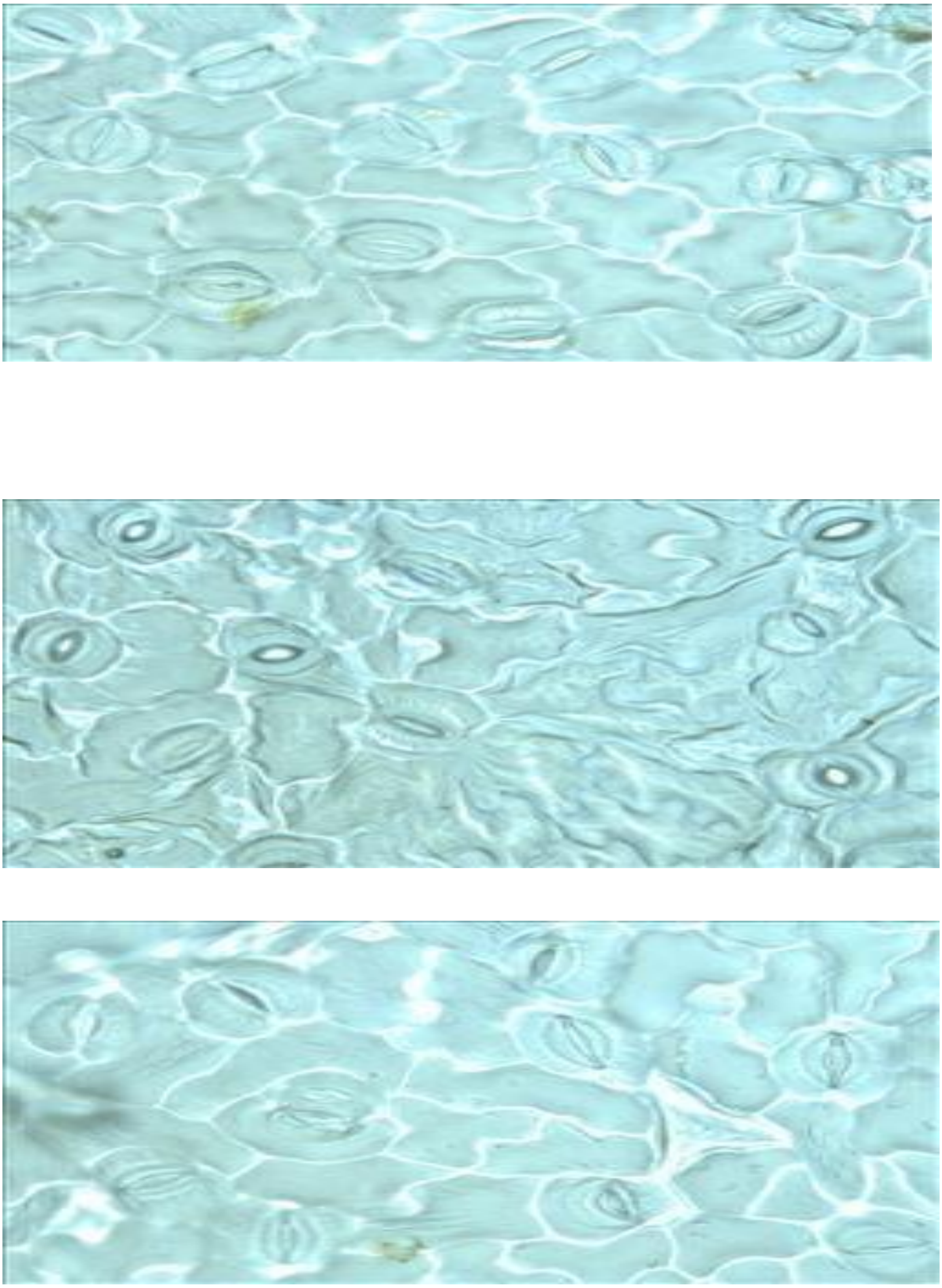

Figure 10. Sweetpotato varieties stomata picture (NASPOT 12 O, Kulfo and Dilla)

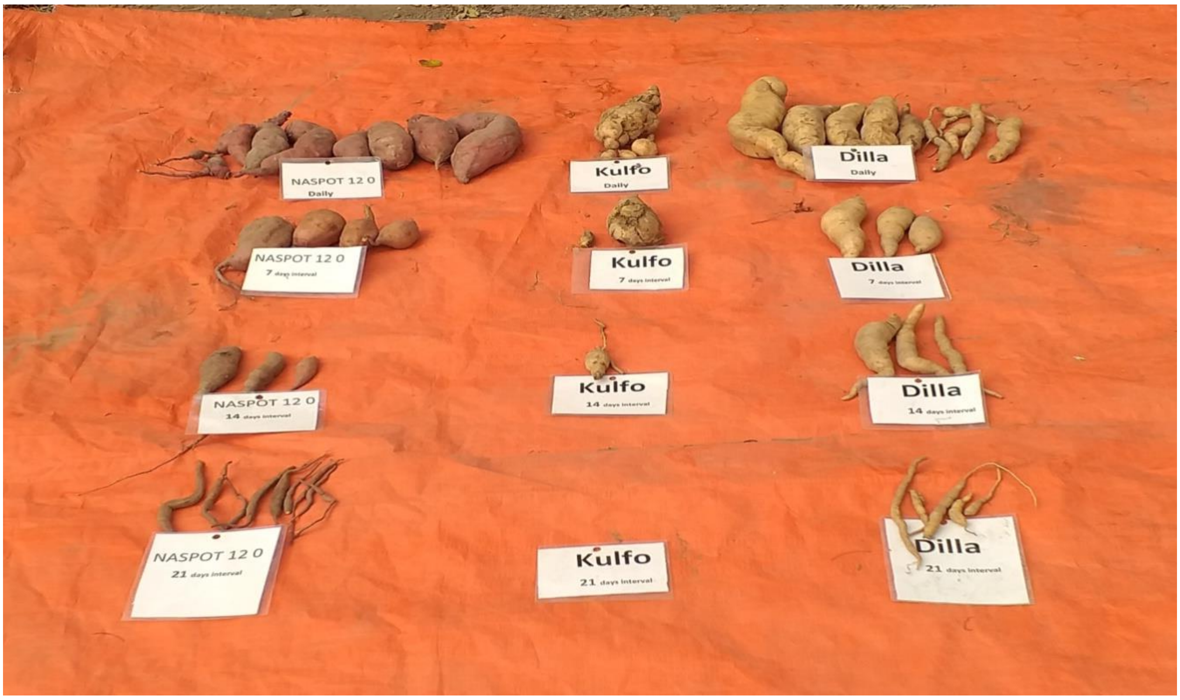

Figure 11. Sweetpotato varieties yield under all treatment

SKETCH OF BIOGRAPHY

The author, Serkalem Eshetu G/wold was born on June 24, 1989 GC at Robe, Bale Zone, Oromia regional state, Ethiopia. At 1995 GC admitted grade 1 and completed her primary education (1-8) at Model and Zeybela primary school. Then after, she attended her high school (9-10) and preparatory school (11-12) at Robe secondary and preparatory school. After completion of University entrance examination, she joined Jigjiga University in 2007 to pursue her first Degree and graduated with BSc Degree in Dry land crop and Horticultural science in July 2009. After her graduation, she had worked at Wondo district agricultural office, until she has got a chance to attend her Master's program. In 2018, she joined the Graduate program in Horticulture at Hawassa University.