ORIGINAL RESEARCH ARTICLE

The effect of water stress on growth and development of mango (*Mangifera indica* L.) varieties in lower Eastern region of Kenya

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ABSTRACT

The relationship between the plasticity of different mango (*Mangifera indica* L.) varieties to soil water stress conditions needs a better understanding as a potential crop adaptation to changing climate. This study was investigated the effects of different water regimes on growth and development of different mango varieties. Measurements of mango plants' morphological and physiological variables during the progressive imposition of soil water stress were performed within a controlled environment. Eight mango varieties were grown under water stress treatments of 90%, 65% and 35% of field capacity (FC) on split plots in a randomized complete block design with three replications. Data on shoot height and diameter, leaf chlorophyll content, temperature and water potential were collected fortnightly, for nine months and means computed to reflect varietal response under increasing water stress (90% FC to 35% FC level). Results showed significant (p=0.001) reduction in shoot height by 32.1% and shoot diameter by 29.05%. A significant (p=0.05) reduction in leaf chlorophyll content and leaf water potential by 13.5% and 90% respectively was observed, while leaf temperature significantly (p=0.05) increased by 20.8%. From the results; Keitt, Sabine, Tommy Atkins and Van Dyke showed better performance in shoot growth and leaf parameters under high water stress. For all varieties, high water stress significantly suppressed shoot growth, leaf chlorophyll content production and increased leaf temperature and leaf water potential. None of the varieties showed optimal phenotypic plasticity on both leaf growth and physiological parameters under highest soil water stress. We emphasize the considerable need of investigating, over a period of at least five years, the effect of water stress on mango yield in the farms located in mango-growing areas.

Keywords: *Mango variety, soil water stress, growth, plasticity, adaptation.*

1.0 Introduction

Moderate water stress can constrain excessive vegetative growth and productivity of mangoes (Shaban & Rashedy, 2020). In tropical and subtropical areas, mangoes can grow well at 700 mm of uniformly distributed annual rainfall, and the crop can withstand dry periods of up to 8 months (Bally, 2006). Understanding and manipulating water-stress tolerance at the scale of ecophysiology can guide farmers on crop adaptation to agro-ecosystems and cultivation. This , can also unveil intra-varietal traits that confer stress resistance, provide a baseline on the crop's distribution, and help improve environmental quality (Shao et al., 2008; Mcdowell et al., 2013). For mango, shoot growth takes place in periodic flushes, which can last for three to six weeks. This is followed by a period of dormancy during which soil-water availability is essential (Rajan et al., 2011). According to Aroca (2013), water stress also disrupts photosynthetic pigments, reduces leaf size, stem growth and overall plant growth. When the soil moisture content is controlled through irrigation at 65–70% of the field water capacity (FC), water demand for the growth and development of mango trees can be ensured (Wei et al., 2017). Mango is considered a drought-tolerant species that is able to withstand seasonal dry periods for up to 8 months (Bally, 2006).

Globally, the fluctuation of temperature, especially rising average maximum temperatures due to climate change is a major factor that affects mango productivity (Khalifa & Abobatta , 2021). In India, the world's top ranked producer faces challenges that include unavailability of quality mangoes in sufficient quantity, unavailability of market information and price fluctuation of the commodity supply (Padaliya, 2023). Elsewhere in Asia (with over 70% of world's production) the main challenges include occurrence of destructive pests and diseases, low profit margin and unstable production are the major challenges. (Paguia, 2021). Similarly in Kenya, insect pests and fungal diseases, poor harvesting techniques and poor marketing which result in large post-harvest losses, are the main challenges (Kehlenbeck et al., 2012). In Kenya, lower eastern is the leading mango production region (Lauri & Legave, 2015). Musyimi et al, (2014) have shown that the wine produced from mango is very similar in aroma and taste to the commercial grape wine, a marketing value addition to the traditional eating of the fresh fruit and juice. Mango has considerable ecological plasticity, as shown by its wide geographical distribution and studies suggest that the crop has physiological mechanisms for coping with stressful environments (Lauri & Legave, 2015). Studies by Njoki et al (2024) in Kitui County in lower eastern region of Kenya shows that temperatures between 29.3 - 33.65°C are moderately to highly suitable for mango growing. The species have adaptive features such as deep tap/sinker roots, tough leaves with thick cuticles to regulate transpiration, and resin ducts to reduce wilting (Bally, 2006). Mango occupies a position of advantage due to its large genetic diversity. According to Griesbach (2003), generally, once a mango tree is well established, it is drought resistant, especially when the taproots have reached the water table. According to Ngulu *et al.*, (2022) there are more than ten improved mango varieties grown in farms in Kenya; therefore it is necessary to determine the influence of soil water stress on growth of different mango varieties. Further documentation on varietal plasticity and adaptation to water stress conditions by mango crop in growth performance, tree health and even yield under water-stress environments is required. This will enhance adoption of the most suitable varieties by farmers in different AEZs. Studies predict that water scarcity will continue to increase in the future, with about 52% of the world's population living in water-stressed regions by 2050 (Kölbel et al., 2018). Due to climate change, there is an increased frequency and severity of water stress occurrence. Understanding the suitability of mango germplasm to changing soil water stress would contribute toward climate-smart agriculture practices. The objective of this study was to investigate the effects of different water regimes on the growth and development of different mango varieties. This was done by comparing variation in growth performance of the mango variety's plasticity to soil water stress whose results can enhance adoption of the most suitable varieties by farmers in different regions.

2.0 Materials and Methods

2.1 Source of Plant material and seedling establishment

The rootstock plant materials of the Sabre mango variety of the same physiological age and shoot size were obtained from one fruit nursery at Kenya Horticultural Fruits Research Station (KALRO) Kandara. The experiment involved seven improved mango varieties (IMVs) Apple, Dodo, Kent, Keitt, Ngowe, Tommy Atkins, Van Dyke, and a traditional landrace named Kasangili. For each of the eight varieties, fifteen strong, free of-pests pencil-sized scions, with healthy 'non-tight' terminal buds, were sourced from similar germplasm in one mango mother block at Kamiti prison orchard, Ruiru, Kenya. A total of 120 Sabre rootstock seedlings were cut horizontally (at 6−8 cm above soil level) and then vertically split at (3cm) deep. The lower end of the 10cm long sterilized scion was sharpened into V-shape (about 2−3 cm), slid into rootstocks, the union tightly wrapped with tape, knotted, and the grafted seedling placed in a net shaded area for 6-8 weeks . The tape was removed after six months, and the success rate was about 80%. For each of the eight varieties, nine successfully grafted seedlings were transplanted into perforated plastic pots and set up in an unheated greenhouse to facilitate water stress experiments. A daily temperature range of 10.2°C–40.5°C was maintained. Seedlings were set up to be established in 30cm radius perforated pots since mango is grown in pit size of 60 × 60 cm with well-drained red loam soil pH of 6.0–7.5 range as essential prerequisites for good development of mango trees in Kenya are preferably pH range from 5.5 to 7.5 (Griesbach, 2003). Each growing mango plant was grown in a pot containing 54 kg of clean red loam soil, organic manure and clean sand in a 5:2:1 (v/v) ratio (Fig. 1b) and all pots were arranged in preset rows in the green house. Soils used for the experiment were evenly constituted and contained nitrogen 0.96%, phosphorous 25.75 mg kg^{-1}, exchangeable potassium 2.5375 *me* 100^{-1}, exchangeable calcium 22.5625 *me* 100^{-1} and electrical conductivity of 0.0725 *mS/cm*. Each pot's soil had pH of 6-7.5, clay content of 35 %, silt 40% and sand 25%. At field capacity, the soil's moisture content was maintained at 90% FC and moisture content at the permanent wilting point was 16.5%. The study was conducted from December 2019 to August 2020 (for 270 days). The pots were separated by 30cm square concrete blocks spaced 1m apart resting on soil surface to avoid cross seepage of water between adjacent pots. During the experiment, the appropriate weeding and fertilizer application in NPK dosage of 0.4-0.2-0.2 kg^{-1} tree^{-1} year^{-1} was applied monthly. Selected insecticides to prevent mites, thrips, leaf scales and mealybugs along with sulphur-based fungicides to control leaf spot, sooty mould and powdery mildew, were applied fortnightly to facilitate optimal mango plant growth.

2.2 Experimental site and design

The experimental greenhouse was at the Horticultural demonstration farm at Jomo Kenyatta University of Agriculture and Technology Juja Kenya. The green house was maintained at internal

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temperature of 20-29°C and relative humidity of 50-70%, these being the conditions for optimal growth of mango (Griesbach, 2003; Khalifa & Abobatta, 2021). The trees were screened for water stress tolerance by varying soil water regimes to determine the sensitivity to soil moisture levels. The seedlings were maintained for nine months to allow growth and establishment before treatments were introduced. All 72 potted plants, in a randomized complete block design, were in the same greenhouse under the same abiotic conditions except soil moisture content (Fig. 1b). The experimental units were three immovable sub-plots, one for each of the three, soil water stress treatment sub-blocks. Sub-block 1 was set at 35%FC soil water stress treatment; and had three replicates for each of the eight varieties, totaling 24 seedlings. Sub-blocks 2 and 3 had similar set-ups at soil water stress treatment of 65%FC and 90%FC, respectively. The soil in each seedling pot was irrigated to field capacity (FC) and the mean soil moisture holding capacity was determined. Soil volumetric water content, relative water content and water deficit were accurately measured once every two days using HydroSense II [HS2P, Campbell Scientific, Inc., Utah USA] – (Fig 1c). The moisture content at 90% acted as the control. Each pot's soil water level was measured every two days and the water deficit (in ml) accurately replenished by irrigation, to maintain the appropriate (90%FC, 65%FC, or 35%FC) soil moisture level.

2.3 Data collection

The leaf water potential - LWP (MPa) was measured early in the morning (6-6:30 am). The 3rd fully expanded leaf from the apex of each plant using Model 3005 Scholander Plant Water Status Console – PWSC (PMS Instrument Co., UTAH, USA). The console was attached to a portable nitrogen (N2) tank at a pressurization rate of 0.05 MPa s^{-1} (Fig. 1d). Freshly cut leaves were enclosed in a cellophane bag in dark and humid dark containers for at least one hour before measurement. The leaf was immediately inserted into a stainless-steel chamber and which was then tightly closed. The N_2 gas was slowly released to increase the pressure inside the of the room gradually and the oozing out of sap was monitored using a lighted hand lens. The pressure gauge's value was recorded when the leaf sap's first emergence was observed (Saha et al., 2016). The LWP reading was taken and the procedure was repeated for each leaf from each mango plant.

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Figure 1 *(a) grafted scions of different mango varieties (b) some of the rows of 8 potted mango varieties exposed to different water regimes (c) measuring soil moisture content using HydroSense II and (d) determining leaf water potential using Scholander Plant Water Status Console.*

The leaf chlorophyll content was determined *in vivo* using a pulse-modulated handheld chlorophyll fluorometer (PAM-2500 Heinz, Germany). The fluorescence, F_v/F_m was determined at pre-dawn before the direct sunlight hit the leaves. F_m represents the maximum fluorescence yield of an illuminated leaf through the saturation pulse method. For leaf chlorophyll, (F_v/F_m) was calculated as $(F_m - F_o)/F_m$ using the pulse-modulated handheld chlorophyll fluorometer, which determined F_m and F_o represent the maximum and minimum fluorescence yield of dark-adapted leaves, respectively (Walz, 2008). The measurements were done for light [at <1 μmol(photons) m^{-2} s^{-1}] using a 0.8 s saturating pulse at 6000 μmol (photons) m^{-2} s^{-1} whereby actinic light of 619 μmol (photons) m^{-2} s^{-1} drive photosynthesis and gives "F". For 5 minutes, the steady state value of fluorescence (F_s) was recorded. After that, a second saturating pulse at 6000 μmol (photons) m^{-2} s^{-1} was imposed to determine F_m in the light-adapted state. F_v was basal fluorescence after 5 μmol) m^{-2}s^{-1} of far- red irradiation at 720-730 nm for 4 s.

Additionally, from the onset of treatments, the Leaf Area Index (LAI) in m^{2} foliage m^{-2} ground was measured using a single wand LAI-2200c Optical Sensor canopy analyzer. The LAI was calculated for each subplot since the lens of LAI-2200c Optical Sensor user-selected zenith and azimuthal angle divisions could not determine LAI for individual plants (LI-COR, 2016). The measurements were done in pairs, 1st transect (across the treatment subplot) with the sensor 'looking' along the row of trees and 2nd with the sensor looking across the row. The LI-190R Quantum sensor was also used to measure photosynthetically active radiation (PAR) in the plants. Data was collected from day 120 to day 270 from the onset of treatment (days after treatment – DAT (reason??). All measurements were performed once a week on the same day between 0600 hours and 1130 hours. The pots were flooded with water for the field moisture capacity and allowed to drain for 24 hours until the gravitational water stopped flowing. The amount of soil water for each pot was measured using the volumetric method. During the experimental period, soil moisture content was maintained at 90% (±5%) field capacity (FC), 65%FC and 35%FC.

2.4 Statistical analysis

The response variables were shoot height (SH), shoot diameter (SD), leaf chlorophyll content (LCHLO), leaf water potential (LWP), leaf temperature (LTEMP) and leaf area index (LAI). The influence of the soil water stress levels of 35%, 65%FC and 90%FC on the individual varieties and the interaction of water stress and variety as a source of variation on plant growth and physiology was statistically analysed. Analysis of variance (ANOVA II) run on SAS software was performed. All numerical data on the development and physiological responses were plotted using SigmaPlot version 14.5 software. Significant differences ($0.001 \leq p \leq 0.05$) in the growth and physiological parameters among the varieties based on soil water-stress levels were determined using a two-way analysis of variance (ANOVA II). Significant ($p \geq 0.05$) differences between means for all shoot growth and physiological parameters at the three different water levels were determined using Tukey's test at $p < 0.05$ level. Since the sample sizes were equal (homogeneity), a Post Hoc least significant difference (LSD) test was used to compare differences between treatment means using SAS software. The relationship between each growth parameter and water-stress, variety and the interaction of water-stress and variety were determined.

3.0 Results and Discussion

3.1 Growth parameters

3.1.2 Shoot height

There were significant ($p=0.05$) differences in shoot height (SH) growth for the three treatments among all the mango varieties (Fig 2a and Table 2). At 90%FC, Keitt grew to the highest (2345mm) mean maximum shoot height while Apple grew to the lowest (1583mm) mean maximum shoot height. Among the seven improved mango varieties, Apple, Dodo, Keitt and Tommy Atkins mean shoot height at 90%FC was significantly greater (1860cm, $p=0.05$) than at higher water stress of 35%FC treatments (1008cm, $p=0.05$) (Fig 2a). Under 90%FC treatment, Van Dyke and Sabine had the greatest (26.6%) and least (11.7%) rates of increase, respectively, while at higher water stress (35%FC) level, Keitt and Sabine had the greatest (37.7%) and least (9.0%) rates of increase over 270 days. These findings agree with a study on mango by Shaban et al. (2020) that moderate water stress (70%FC) decreased shoot height. Other studies found that water deficit and water stress in the plant inhibit cell division, enlargement and differentiation and reduce plant size, including shoot height (Allen et al., 2010; Farooq et al., 2012; Shao et al., 2008). Further studies have found that more water in the root zone boosts the movement of macro-element from the soil into the plant, enhancing shoot growth (Tahir et al, 2003; Shah et al, 2018). Conversely, reduced soil water likely means shortages of nutrients absorbed by the roots and reduced shoot growth rate.

3.1.1Shoot diameter

There were significant ($p=0.050$) differences in the growth of shoot diameter for the three treatments among the mango tree varieties (Fig 2b and Table 2). There was more significant ($p=0.050$) shoot diameter growth at 90%FC than at 35%FC between 120 and 270 days after treatment (DAT). At 90%FC treatment on 270 DAT, Dodo grew to the highest (46.8mm) mean maximum shoot diameter, while Tommy Atkins grew to the lowest (30.1mm) mean maximum shoot diameter (Fig. 2b). For Sabine and Tommy Atkins, the mean shoot diameter at 90%FC was significantly ($p=0.05$) greater than at higher water stress (35%FC) treatments by 27.3% and 20.1%, respectively. At 90%FC, Tommy Atkins and Apple had the greatest (38.0%) and least (24.3%) rates of increase, respectively, while at 35%FC, Dodo and Keitt had the greatest (32.0%) and least (21.5%) rates of growth. These findings agree with studies on the Keitt mango variety by Shaban et al (2020) which found that the plants had decreased shoot diameter under moderate water stress (70%FC), which may be a mechanism to alleviate drought stress. Various studies have found that low water stress significantly increases the shoot diameter of mango trees (Fahad et al., 2017).

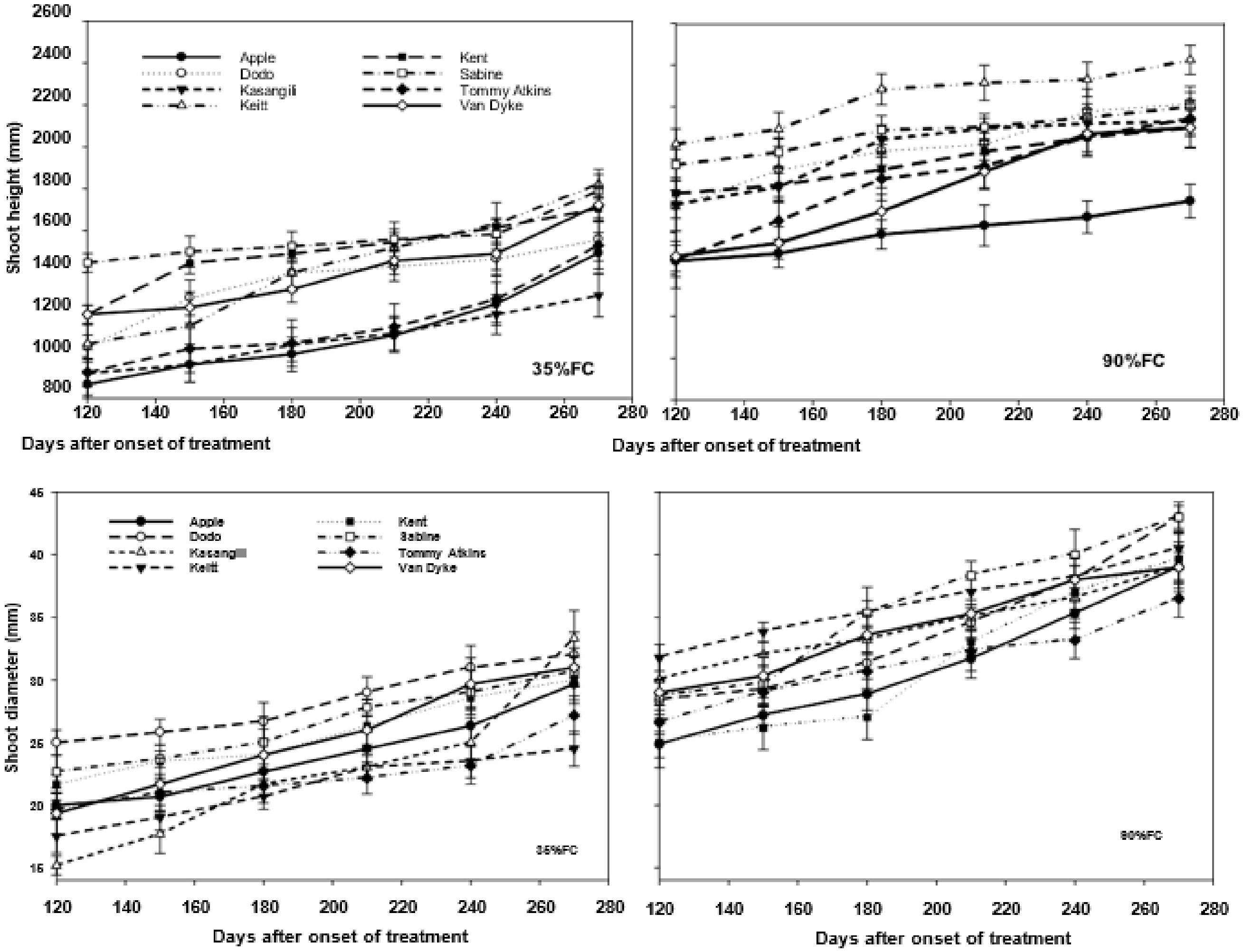

Fig. 2 (a – top and b) The variation of the mean (of three replicates) monthly shoot height (top) and diameter (bottom) for two of eight mango varieties as affected by two extreme water stress levels of 35%FC and 90%FC (data for 65%FC which was in the middle was excluded). Vertical bars indicate the standard errors of the means. n=3.

3.2 Physiological parameters

3.2.1 Leaf chlorophyll content (LCHLO)

For all varieties except Apple, there was greater ($p=0.050$) leaf chlorophyll content at 90%FC than at 65%FC or 35%FC between 180 and 270 days after onset of treatment (Figure 3 and Table 2). Apple and Kent had the highest mean leaf chlorophyll content of 110 µmol m^{-2} s^{-1} at 35%FC, while

Dodo and Sabine had the highest of 133 µmol m–2 s–1 at 90%FC. An increase in water stress (from 90%FC to 35%FC) significantly (p=0.05) reduced (by 13.5%) mean leaf chlorophyll content. This is contrary to studies by (Shaban et al., 2021), which found that increased water stress increases the leaf chlorophyll content in the Keitt mango variety. With over 25 mango varieties in Kenya, it can be expected that there could be both drought-tolerant genotypes and drought-sensitive genotypes. Components of the photosynthetic apparatus PSI and PSII could be damaged more significantly in drought-sensitive genotypes than in drought-tolerant genotypes. Water stress may result in irreversible chlorosis, a decline in active leaf longevity, and reduced leaf expansion. However, increased leaf temperature reduces photosynthetic efficiency and effectively reduces overall growth (Efeoğlu et al., 2009; Hussain & Ali, 2017). Since Apple and Kent varieties were least negatively affected by water stress, the varieties appear to be more suited to retain chlorophyll and photosynthesize best in the drier agro-ecological zones (AEZs). Among the IMVs Sabine variety had the highest chlorophyll (133 µmol m^{-2} s^{-1}) in the 90%FC treatment and one of the lowest (101 µmol m^{-2} s^{-1}) in the 35%FC and is, therefore, best suited for the more humid areas.

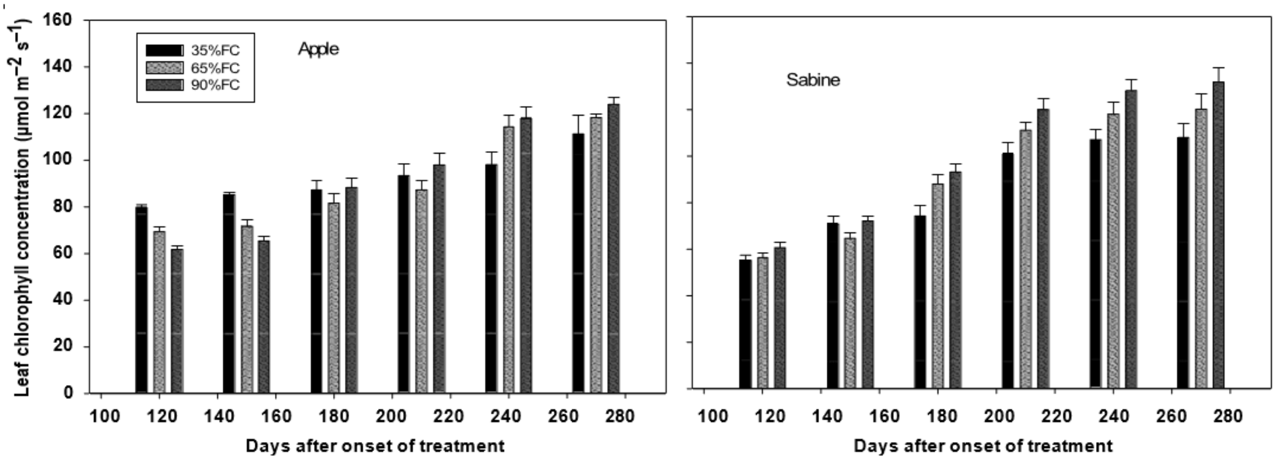

Fig. 3 Leaf chlorophyll concentrations for eight mango varieties as affected by water stress levels of 35% FC, 65%FC and 90%FC. Columns represent the means of three replications. Vertical error bars indicate the standard errors of the means. n=3.

These results contradict a study on mango by Shaban et al. (2020), which found that leaf chlorophyll content increased under moderate water stress (70%FC). Studies by Song et al (2014) through chlorophyll fluorescence analysis on the poplar plant (*Populus euphratica*) showed that high-temperature treatment over twelve hours might cause permanent inhibition of photosynthesis since photosystems could be inhibited and photosynthesis cannot ultimately return to normal levels. Research findings on apple trees by Wang et al (2018) indicated that when leaf water potential is above -1.5 MPa at moderate to low water stress, the stomatal limitation should be the main reason for a drop-in photosynthesis. However, under severe water stress, a drop in photosynthesis was found to be due to non-stomatal limitations such as changes in root or shoot growth, leaf area, and chlorophyll concentration (Wang et al., 2018; Xu et al., 2010). Chlorophyll fluorescence is closely related to the photosynthetic efficiency, and the influence of environmental factors on photosynthesis can be diagnosed by chlorophyll fluorescence (Xu et al., 2020). According to Zushi et al. (2012), damage to PSII reaction centers occurs under drought stress, affecting the photosynthetic electron transport process. Leaf area and leaf area index (LAI) determines a crop's light interception capacity.

3.2.2 Leaf water potential (LWP

For all varieties, generally, the LWP of the most stressed (35%FC) plant varieties was significantly lower (p=0.050) than that of the 90%FC plants. LWP decreased (became more negative) for all water stress treatments, albeit with a slight increase at the end of the experimental period. The minimal mean values of between -3.67 and -5.67 MPa were recorded for Tommy Atkins and Kent varieties. Kent variety had the lowest mean LWP (-4.75 MPa) under severe water stress. Tommy Atkins was the most resilient to increased water stress and the only variety (of all eight) whose LWP never declined to below -4.0 MPa under the greatest water stress (35%FC) compared to the range of a mean of -2.5MPa in the least (90%FC) water stress. This is close to the findings by Cotrim *et al.*, (2011), where Tommy Atkins LWP values were -

2.0 MPa under high water stress (35%FC). In conditions of greatest water stress, this variety's minimum LWP of -3.8 MPa was well above the mean of -4.1 MPa for all the other varieties. Tommy Atkins appears the most tolerant to high water stress and is more suitable for drier AEZs. According to studies by Kaya et al (2011) on olives, which, like mango, are frequently subjected to high temperatures and water scarcity, their leaves tolerate extremely low total water potential (-10 MPa). According to this study, LWP values do not differ between tolerant and susceptible genotypes under well-watered conditions (90%FC), but under stressful conditions (35%FC) tolerant genotypes show a lesser reduction in LWP than susceptible genotypes. Kent variety was the least tolerant and hence least adapted to water stress (mean of -4.75 MPa at 35%FC treatment) and is not suitable for the drier AEZs. Consequently, Kent would require more irrigation than Tommy Atkins. According to studies by Maréchaux et al. (2015), leaf water potential at a wilting point is a determinant of the tolerance of leaves to water stress and contributes to plant-level physiological drought tolerance. Kent variety was least adapted and unsuitable for growing in drier AEZs, considering its large leaf surface area which potentially increases the evapotranspiration rate. The results are in agreement with findings by Shah et al. (2018) that for mango plants, receiving more amount of irrigation water may increase the water in root zone which ultimately boosts the movement of macro-element from the soil. Leaves with more negative leaf water potential remain turgid and maintain photosynthetic gas exchange under increased water stress conditions (Guyot et al., 2012). Water stress causes a decrease in lower canopy LAI as an adaptation strategy and strongly influences canopy photosynthesis (Weraduwage et al., 2015; Smith et al., 2019).

3.2.3 Leaf temperature (LTEMP)

Leaf temperatures for more water-stressed plants were significantly higher than in the least water-stressed plants for all eight varieties, as is partly shown in selected graphs (Fig. 4). Leaf temperature (LTEMP) was significantly (p=0.050) increased at 35%FC treatments by a mean of 20.8%, compared to 90%FC for all eight varieties. At 35%FC treatment, Apple and Sabine had the highest (30.36ºC) and the lowest (27.19ºC) mean LTEMP, respectively, during the experimental period. At 90%FC, Apple mango had the lowest mean (27.19ºC) LTEMP. Sabine variety is the most tolerant to high water stress and more suitable for drier areas since its leaf temperature remains relatively low. This would have a less negative influence on enzymes and photosynthesis. After an initial slight increase, leaf temperature generally decreased for the rest of the experimental period for all varieties. Studies by Miranda et al. (2019) on pequi trees (*Caryocar brasiliense*) found that thermal gradients between the leaf and air average temperatures were 1.20°C and 1.50°C, respectively. In contrast, else with irrigation, the average thermal gradient fell to -2.00°C. According to Ivanov et al. (2017), high temperatures can cause direct damage to photosystem II (PSII), which is generally considered the primary target of heat-induced inactivation of photosynthesis. The temperature of a leaf is modified by transpirational cooling, and the rate of transpiration is influenced by the ambient atmospheric temperature, which affects plants physiological status (Dhyani & Purohit, 1988, Gupta et al., 2018). Further, the effects of elevated temperatures on PSI might be vital for regulating the photosynthetic response of all photo-autotrophs and have significant implications on photosynthesis under future climate change scenarios (Ivanov et al., 2017). Leaf temperature as an indicator of water stress is useful, but the specific gradient value based on which physiological changes occur depends on the sensitivity of the plant to water deficit. Logically reduction in soil water is expected to cause partial or full stomatal closure to reduce transpiration and this leads to increase in leaf temperature. Increase in leaf temperature due to water stress might be attributed to low transpiration rate under high water stress levels.

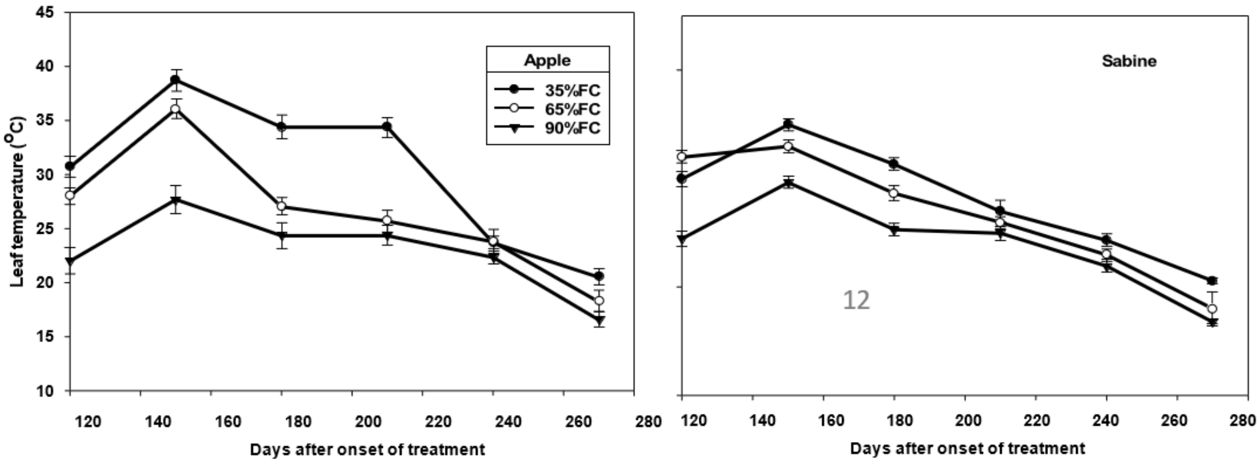

Fig 4 *Variation of mean monthly leaf temperature of two (representative sample) of the eight mango varieties showing effect of water stress levels of 35% field capacity (FC), 65%FC and 90%FC. Vertical bars indicate the standard errors of the means. Each value is the mean of measurements of three replicates. n=3.*

3.2.4 *Effect of water stress on growth and physiological parameters of mango plants*

Soil water stress level, variety and their interactions between water stress and variety had a strongly significant ($p \leq 0.001$) effect on shoot height (SH) and shoot diameter (SD) of mango seedlings throughout the experimental period (see Table 1). Shoot height and shoot diameter were significantly higher ($p=0.05$) at 90% field capacity (FC) than at 65%FC and 35%FC throughout the experimental period (Table 2). There were significant ($p=0.05$) differences in the shoot height and diameter between the varieties at all the water stress levels. According to Table 1, variety or the interaction of water stress and variety did not have a significant influence (at $p=0.001$) on leaf temperature and water potential only for most part of the experimental period. These results (Table 2) show that under 35%FC and 65%FC water stress conditions, Keitt achieved the greatest shoot height. An indication of Keitt's greater suitability, compared to the rest, to grow in a wider cross-section of the agro-ecological zones that experience increased water stress. The plants showed a significant ($0.001 \leq p \leq 0.05$) positive correlation between SH and SD throughout the experimental period. This study found that increased water stress significantly ($p=0.001$) reduced shoot height and diameter of all eight mango varieties. Water stress had a strongly significant effect on leaf temperature throughout the experimental period. Soil water stress levels significantly affected leaf chlorophyll content throughout the experimental period (Table 1). Our results show a significant difference in shoot height and diameter, leaf chlorophyll and temperature between plants under severe water stress and those under low water stress throughout the experimental period (Table 2). As stress increases, leaf chlorophyll content decreases for all varieties.

It is expected that plant growth rates vary among different mango varieties due to differences in plasticity in drought avoidance potential. Studies by Xue *et al.*, (2018) on *Cassia obtusifolia* L. found that shoot height of the trees subjected to 60% and 40% of FC water deficit treatments decreased by 17.01% and 35.85%, respectively. Under low water stress, plants absorb more water and nutrients than the roots of the more water-stressed plants and this can increase shoot growth in both height and diameter. Photosynthesis of higher plants decreases with the reduction in leaf water potential (Lisar et al., 2012). Also, plants react to increased water stress by reducing the transpiration rate to conserve water in the plant and this could lead to an increase in leaf temperature.

Table 1 *Tree growth and physiological parameters as influenced by soil water stress level, variety and interaction of water stress and variety for eight mango varieties.*

Days after onset of treatment	Source of variation	Shoot height (mm)	Shoot diameter (mm)	Leaf chlorophyll (µmol m^{-2} s^{-1})	Leaf water potential (MPa)	Leaf temperature (°C)
120	water-stress	0.0045	0.0015	0.0317	<.0001	<.0001
	variety	ns	ns	ns	ns	<.0001
	Waterstr*vty	ns	0.0033	ns	ns	0.0327
150	water stress	0.0004	0.0033	ns	ns	<.0001
	variety	ns	ns	ns	ns	ns
	Waterstr*vty	ns	0.0107	ns	ns	ns
180	water stress	0.0011	0.0006	ns	ns	<.0001
	variety	ns	ns	ns	ns	ns
	Waterstr*vty	ns	0.0030	ns	ns	ns
210	water stress	<.0001	0.0002	ns	*	<.0001
	variety	ns	ns	ns	ns	ns
	Waterstr*vty	ns	0.0058	ns	ns	0.0006
270	water-stress	<.0001	0.0002	0.0006	ns	0.0001
	variety	ns	ns	ns	ns	ns
	Waterstr*vty	ns	0.0405	ns	ns	ns

Water stress and variety interaction (waterstr*vty). Significance at P≤0.05, ≤0.01, ≤0.001 by Tukey's test. n=3.

Table 2 Growth and physiological parameters of shoot height, shoot diameter, leaf chlorophyll content, leaf water potential and leaf temperature of eight mango varieties under three soil water stress levels (35% field capacity (FC), 65%FC and

90%FC). For the significant interaction effects LSMEANS was used for mean separation. n=3

Days after onset of treatment	Treatment	Shoot height (mm)	Shoot diameter (mm)	Leaf chlorophyll (µmol m^{-2} s^{-1})	Leaf water potential (MPa)	Leaf temperature (^{o}C)
120	35%FC	1121.5a	20.1a	62.69a	3.56a	25.20a
	65%FC	1422.0b	24.0b	64.08a	2.99a	23.95b
	90%FC	1724.4c	28.0c	69.00b	2.93a	20.48c
	LSD	70.18	1.02	4.20	1.01	2.82
150	35%FC	1202.9a	21.6a	69.92a	3.96a	29.04a
	65%FC	1515b	26.0b	70.17a	2.98b	36.17b
	90%FC	1828.1c	29.8c	70.79a	2.35b	39.37c
	LSD	68.35	0.99	5.34	0.78	2.52
180	35%FC	1245.2a	23.5a	87.63a	3.72a	33.29a
	65%FC	1588.3b	27.1b	95.58a	2.87ab	27.71b
	90%FC	1902.7c	31.3c	95.67a	2.44b	27.76c
	LSD	67.09	7.96	9.15	1.16	1.38
210	35%FC	1350a	25.0a	81.37a	3.31a	30.12a
	65%FC	1637.5b	29.1b	93.13a	2.71a	27.67b
	90%FC	1985.0c	33.6c	110.13b	2.66a	27.79c
	LSD	48.5	0.94	10.0	0.78	1.03
270	35%FC	1575.2a	28.5a	104.67a	2.41a	20.6a
	65%FC	1757.0a	32.7b	113.25b	2.14a	18.32b
	90%FC	1984.6b	39.2c	122.54c	2.00a	20.63c
	LSD	22.0	3.91	4.5534	2.15	0.4583

For treatments on a given date after onset of treatment, means followed by the same letters do not differ significantly by Tukey's test (p=0.05) and according to the LSD. n=3

Further, more water in root-zone would facilitate the movement of soluble macro-elements from the soil into the plant, enhancing shoot growth. Increased water stress causes chlorophyll to decrease, probable photodamage of PSII, increased stomatal closure and increased leaf water potential, so rate and total photosynthesis falls. The expected result is a decline in the quantity of carbohydrates and, consequentially a reduction in shoot height and diameter. According to Seleiman et al., (2021), drought causes oxidative damage in the chloroplast, slowing down photosynthesis and consequently slowing down plant growth. Similarly, a study by Medrano et al. (2002) on Mediterranean shrubs had shown that despite interspecific differences, they all followed the same pattern of dependence of photosynthetic processes for all C3 plants under drought. Morphological plasticity in root growth can cause an increase in water use efficiency for shoot dry matter in response to water stress to mitigate drought risk in arid areas (Cai et al., 2017).

3.3 Correlation analysis

Like Apple, Dodo showed a significant strong correlation ($r=0.75993$, $p<0.05$) between leaf temperature and leaf chlorophyll content by the end of the experimental period. All leaf physiological parameters showed significant and strong correlations ($r=1.0$, $p<0.0001$) for Keitt variety as water stress increased (from 65% towards 35%FC). These included leaf chlorophyll and leaf water potential; leaf chlorophyll and leaf temperature; and leaf water potential and leaf temperature. This is an indicator, just like for Apple and Dodo, of soil dryness's negative effects on the leaf's physiological development. The significant and strong correlation ($r=-0.88087$, $p<0.01$; 0.71424, $p<0.05$) between leaf water potential and shoot height and diameter, respectively, indicates the variety's tolerance level to water stress. Similarly, Kent variety under high water stress showed significant and strong ($r=1.0$, $p<0.0001$) correlation between leaf temperature and leaf water potential. A correlation of equal significance and strength was found between leaf temperature, leaf water potential, and chlorophyll content at medium water stress (65%FC). High coefficients for leaf chlorophyll and leaf water potential ($r=0.99692$, $p<0.05$); leaf chlorophyll and leaf temperature ($r=0.99692$, $p<0.05$); and leaf water potential and leaf temperature (1.000, <0.0001) were observed for Sabine variety. Similar correlation values for those parameters were registered for Tommy Atkins and Van Dyke varieties at all water stress levels. Overall, there was also significant and relatively strong correlation (range from $r=0.34356$ to $r=0.47789$, $p<0.0001$) between shoot height and shoot diameter at all water stress levels. For all varieties, a significant and relatively strong negative correlation ($r=-0.44126$, $p<0.05$) between shoot diameter and leaf water potential found was indicative that a wider stem could be a facilitator transportation of more soil water to the leaves. It needs

3.4 Leaf area index

Leaf area index (LAI), which is the estimated area of leaves over a unit of land (m^{-2} m^{-2}), has been observed to decline linearly with increased water stress (Battaglia et al., 1997; Samant et al, 2021). LAI mean minimum and mean maximum decreased from 2.27 and 4.37 under low water stress (95%FC) to 0.25 and 1.75 under high water stress (35%FC), respectively for all varieties (Fig 5). According to study findings by Samant et al, (2021) an average mango tree has a minimum LAI of 1.20 $m^{-2}m^{-2}$. An increase in water stress (from 95%FC towards 35%FC) resulted in a significant decrease in LAI for all varieties throughout the experimental period. This agrees with studies on Eucalyptus sp. and other forest trees, which showed that LAI declined linearly with increased water stress with a lag of one year (Dantec et al., 2000). According to a study on mango plants by (Samant et al., 2021), LAI plays a vital role in determining plant yield and canopy interaction with light is critical for enhancing photosynthesis and plant growth. These results are in agreement with a study on mango by Shaban et al (2020), which found that conditions of moderate water stress (70%FC) the leaf area decreased where else at reduced water stress (85%FC) there was increased number of leaves and leaf area.

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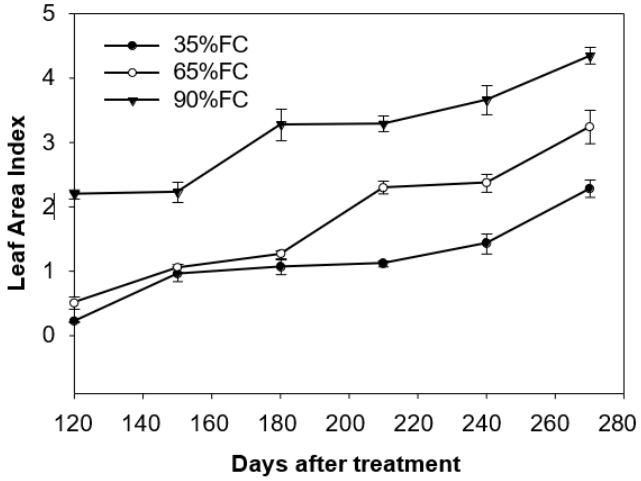

Fig 5 *Leaf area index values of eight mango varieties as influenced by three water stress levels of 35% field capacity (FC), 65%FC and 90%FC. Vertical bars indicate the standard errors of the means. n=3.*

According to study findings on cassava by Alves & Setter (2004), leaf area is determined by both genetics and prevailing environmental factors. It is drastically decreased in response to induced water stress to reduce transpiration and maintain plant productivity. Considering that there was only one canopy stratum in this experiment, it's expected that leaf loss increases due to water stress, supported by study findings that the upper canopy LAI of trees increased during the dry season (Smith et al., 2019). The decrease in LAI and chlorophyll content contributed directly to the decrease in solar radiation intercepted by leaves, thereby reducing dry matter production and consequently reducing shoot height and diameter. According to a study on mango trees by Samant et al, (2021) with increasing leaf area index, productivity (including shoot height and diameter) decreases. This is due to the reduced light distribution in the canopy unless canopy center opening, pruning, thinning out has been done. The leaf area index is a crucial structure for tree ecosystems, and green leaves' critical role in photosynthesis makes an accurate estimation of LAI necessary for studying ecophysiology (Ghoreishi et al, 2012).

4.0 Conclusion

According to this study, Keitt variety had the best growth of shoot height and diameter under all water stress levels and may have the best growth in the varied AEZs. Apple exhibited more resilience to retain more chlorophyll under water stress (35%FC) which could confer the variety advantage in photosynthesizing in drier areas. Under severe water stress, Sabine maintained the lowest leaf temperature and good potential for being adapted to drier areas. Kent variety had the lowest LWP under severe water stress and the greatest drop in LWP as water stress levels decreased. This implies Kent, also having the largest leaf surface, which favours a high transpiration rate, is unsuitable for drier and/or hotter areas. Tommy Atkins has the highest LWP under severe water stress and is more suitable for drier areas since it has the best tolerance to severe water stress. Since mangoes are grown in wide-ranging AEZs from semi-arid to humid areas, establishing which varieties are better suited to grow in specific AEZs is helpful to farmers. Such results can be used to model on-field anticipated performance by each variety in future climate change scenarios. Extending the investigation to sample demonstration field farms in each of the six main mango-growing AEZs would allow all roots to spread naturally, unlike in pots, giving a better indication of the plant's tolerance to water stress. The study recommends conducting field investigations for five to six years to provide an opportunity for determination of the effect of water stress on yield, which is the ultimate interest to mango farmers.

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