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ORIGINAL PAPER

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MITIGATION OF EXCESSIVE SOLAR RADIATION AND WATER STRESS ON 'KEITT' MANGO *Mangifera indica* TREES THROUGH SHADING

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ABSTRACT

Excessive solar radiation "global warming" and water scarcity are consider the main environmental constraints for plant growth and production under arid and semi-arid regions. The current research was aimed to study the effect of irrigation levels (100%, 85%, 70% of irrigation requirements), and shading levels (60%, 40%, 0%) on the growth and productivity of 'Keitt' mango trees. This experiment was conducted during two growing seasons (2016/2017 and 2017/2018) at El Behera Governorate, Egypt. Decreasing irrigation level (IR) decreased leaf area, malformed panicle, powdery mildew infection, final fruit set, fruit numbers, yield but it increased chlorophyll content, proline content, leaf water content. While, increasing shading levels (SH) increased leaves number, leaf area, fruit set, powdery mildew infection, malformed panicle but it decreased fruit sunburn damage, proline content, chlorophyll content and relative water content. Moreover, accumulative effects of 85% IR + 40% SH significantly increased leaf area, fruit set, fruit number, yield, chlorophyll content, WUE, proline content, relative water content, leaf water content while decreasing powdery mildew and sunburn damage. Results suggest that shading at 40% increased the yield up to 20% and decreased sunburn damage up to 0% under irrigation level of 70%. Shading may be a new technique to alleviate the adverse effects of water stress beside their role in avoiding excessive solar radiation on 'Keitt' mango trees.

Key words: chlorophyll, malformation, powdery mildew, proline, sunburn, irrigation

INTRODUCTION

Mango (*Mangifera indica* L.), belongs to Anacardiaceae family. It was cultivated in the tropical then sub-tropical area. Mango is one of the top five fruit crops worldwide with global production around 50 million tons in 2017 [FAOSTAT 2019]. Nowadays, 'Keitt' mango trees are widely spread in the desert of Egypt with average midday temperature more than 35°C and solar radiation in full sunlight 28 MJ m^{-2} during the summer months (CLC, 2018). The fruit needs to long season (6 months) for maturity which demanded more irrigation requirements and subjected the fruit to sunburn damage.

Humanity is facing global water scarcity. Demand of water usage is expected to outstrip supply by 40% in 2030 [Dalberg Global Development Advisors 2014]. Human faces a major challenge in meeting the future increase of water demands such as population number and their needs for newly cultivated lands under global warming resulting from climatic changes with almost fixed amount of water resources. In arid and semi-arid region like Egypt for low and erratic rainfall, irrigation is the common practiced. However, water resources in Egypt are scarce to face the increasing demand for agricultural, industrial users etc. The main goal of recent

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agriculture is conserve water through using less irrigation water for optimum water use efficiency (WUE), yield and fruit quality.

Effects of deficit irrigation water is a complex equation depending on the stage of tree growth, cultivar and environmental region. In India, reduction in irrigation level of 'Tommy Atkins' mangoes at flower induction stage results in lower values of photosynthesis, transpiration and leaf water potential. While, pre-flowering water shortage improved flowering and fruit yield. Also, reduction in irrigation level at 0% or 25% ET_c in the flowering stage and 100% ET_c in the fruiting phase are suitable for floral induction [Faria et al. 2016]. Furthermore, in China, Wei et al. [2017] observed that irrigation 'Guifei' mango trees at 65%–70% of field capacity recorded the highest fruit yield and WUE compared to high (79–82%, 75–78%, 71–74%) or low irrigation levels (63–66%). On the other hand, in Australia, Simmons et al. [1995] found that water deficit during mango flowering and initial fruit set reduced fruit growth and size. Also, water shortage prior to harvest reduced mango fruit weight Bithell et al. [2010] at Australia and numbers Léchaudel and Joas [2007] at Spain.

Climatic changes led to long periods of excessive irradiance which can cause water deficits due to reduce the light-use efficiency, net CO_2 assimilation, WUE, which restricts plant growth, yield and fruit quality [Goldschmidt 1999]. Egypt is located in an arid to semi-arid region [El Kenawy et al. 2019], where water deficit is considered the major environmental factor constraints plant growth and productivity [Boyer 1982]. Shading as environmental friendly technique used to alleviate excessive irradiance. Also, shading of 'Nam Dok Mai' mango trees maintaining high photosynthetic activity which increased fruit numbers [Jutamanee and Onnom 2016]. Furthermore, in Egypt, Medany et al. [2009] found that white netsignificantly increased growth, flowering and yield of 'Keitt' mango trees. Moreover, in South Africa, Mthembu [2001] found that light shading (20%) for 'Kent' mango increased yield and fruit number while heavier shading (50%) decreased it.

Conversely, where the deficit irrigation is a common condition under arid and semi-arid condition. Beginning a question in the mind, under excessive solar radiation and global warming, which increase plant water requirements, can shading practices alleviate detrimental effects of deficit water in 'Keitt' mango tree and conserve water without affecting yield and fruit quality?

MATERIAL AND METHODS

Experimental conditions

This experiment was performed during two growing seasons (2016–2017 and 2017–2018) on eight years-old 'Keitt' mango trees, grown on 'Sukkary' mango rootstock. Trees were placed at 2.5 × 4 m in sandy soil located at El Behera Governorate, Egypt (30°41'42"N and 30°23'16"E, elevation 9 m). Trees were subjected to the common horticultural practices and received the following treatments of three irrigation requirement levels (IR) (100% IR, 85% IR and 70% IR) and three shading (SH) levels (60% SH, 40% SH and 0% SH). Each treatment consisted of three replicates, each one contain 3 trees.

Irrigation requirements (IR) were calculated according to [Allen et al. 1998, Abdrabbo et al. 2013] (equation 1).

$$IR = K_c \cdot ET_o \cdot LF \cdot IE \cdot R \cdot \text{Area (Feddan)}/1000 \quad (1)$$

where:
IR – irrigation requirement (m^3/feddan (1 feddan = 4200 m^2),
K_c – crop coefficient (dimensionless),
ET_o – reference crop evapotranspiration (mm/day),
LF – leaching fraction (assumed 20% of irrigation water),
IE – irrigation efficiency of the irrigation system in the field, (assumed 85% of the total applied),
R – reduction factor (60% cover in this study),
Area – the irrigated area (one feddan = 4200 m^2),
1000 – to convert from liter to cubic meter.

Experimental design, irrigation and shading treatments

Irrigation and shading treatments were started at 5 November 2016 (the time of flower bud induction and differentiation in mango grown in Egypt) till harvesting the second season at November 2018.

Tree received 12.5 m^3, 10.62 m^3 and 8.75 m^3/tree/year for 100%, 85% and 70% IR, respectively. In addition to 57 mm as annual rainfall in both seasons. Drip irrigation was located in a double line parallel to the tree row. Each irrigation level was in separate row (three rows) in parallel to the tree row. While, each shade net level covered horizontally the rows. Seven trees were included in each treatment but only the three of the center used for data recording while the other four trees used as border.

The tree rows were covered with one of the following white shade netting (Polysack Plastic Industries, China) 60%, 40%, 0% (150, 200 cm^2, without shad, respectively) at an altitude of 4 m from the soil surface. The maximum and minimum air temperatures beside air humidity under the different levels of shading were measured weekly using (HTC-2, China).

Twenty random branches were selected from each tree for determine the vegetative and flowering measurements (total 60 branches for each treatment). Flowering measurements which include percentage of powdery mildew infected panicles and percentage of malformed panicles. Also fruiting measurements, include initial and final fruit set were determined when all flowers abscised but remained attached with the panicle and as number of fruits per panicle two weeks after petal fall and at harvest, respectively. All tree brunches were used at maturity stage for determine number of fruits per tree which was counted, yield (kg $tree^{-1}$) and percentage of sunburned damage fruits were determined. During August, leaf numbers were counted and leaf area (cm^2) was measured in 30 leaves per treatment using the following equation: leaf area = 0.70 (leaf length × leaf width) + 1.06 [Ahmed and Morsy 1999]. Also, thirty leaves per treatment were used for physiological parameters which include chlorophyll concentrations were color-metrically determined using Minolta SPAD-502 (made in Japan). Leaf proline content (µmoles/g) was determined using the ninhydrin reaction according to the method of Bates et al. [1973]. Relative water content (RWC) and the leaf water content (LWC): leaves were taken from mature leaves (the fourth distal adult leaf). The leaves were weighed, soaked in water for 45 minutes and dried at 70°C for 24 hours then RWC had been calculated according to Nomier [1994] (equation 2).

$$RWC = ([FW - DW] / [TW - DW]) \times 100 \quad (2)$$

Leaf water content (LWC %) had been calculated according to [Barrs 1968] as the equation 3.

$$LWC = ([FW - DW] / [FW]) \times 100 \quad (3)$$

where: FW – fresh weight, DW – dry weight, TW – turgid weight after immersion in distilled water for 24 hour.

Water use efficiency was determined as follows: Water use efficiency (kg/m^3) was calculated according to FAO [1982] as equation 4.

$$WUE = Y (kg) / WR (m^3) \quad (4)$$

where: Y – yield and WR – water requirements

Statistical analysis

Test of normality distribution was carried out according to Shapiro and Wilk [1965] method, by using SPSS v. 17.0 [2008] software package. A split plot design in a randomized complete block arrangement was used with three replications. The main plots were allotted to the irrigation levels and while shading levels were devoted to sub-plot. The treatment means were compared by least significant difference (L.S.D.) test as given by Snedecor and Cochran [1976].

RESULTS

Microclimatic data

From climatic data (Figures 1, 2 and 3), it can be show that, relative humidity increased from October to April (from harvest to initial fruit set period) in both seasons. Microclimate was influenced by shading, since there was an increase by 1–3°C at 40% and 60% compared to the unshaded control during the winter months, while temperatures was dropped with the same values during the summer months (fruit growth period). On the other hand, increasing shading cases, increasing relative humidity (RH) by 1–8% during summer and by 2–6% during winter months specially under 60% SH.

Vegetative growth

Leaves number. Irrigation level has no significant difference on leaves number (Tab. 1). On the other hand, 40% SH increased leaves number significantly compared to un-shaded ones. For the interaction, 100% IR + 60% or 40% beside 85% IR + 40% SH increased leaves number.

Leaf area. The lowest level of irrigation (70%) or shading (0%) reduced leaf area compared to the other

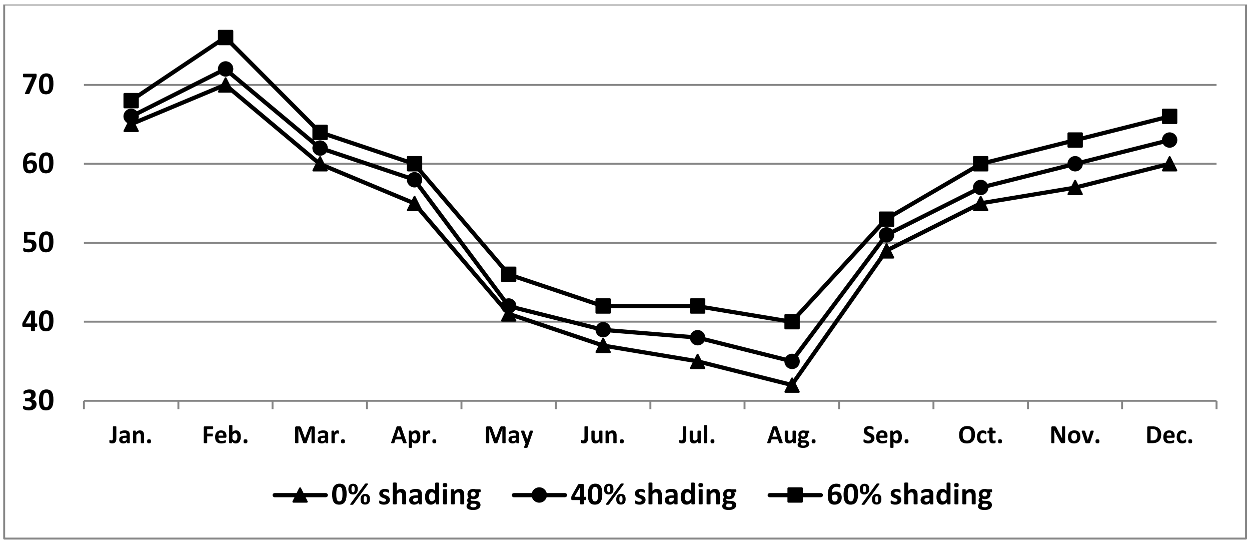

Fig. 1. Average relative humidity (%) under 0, 40, and 60% shading levels

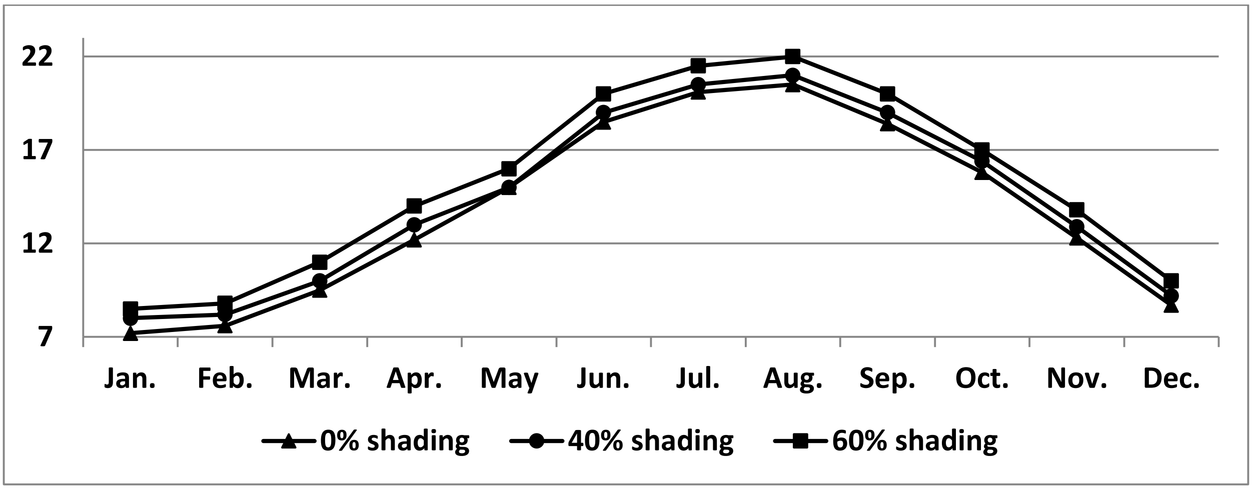

Fig. 2. Minimum temperature (°C) under 0, 40, and 60% shading levels

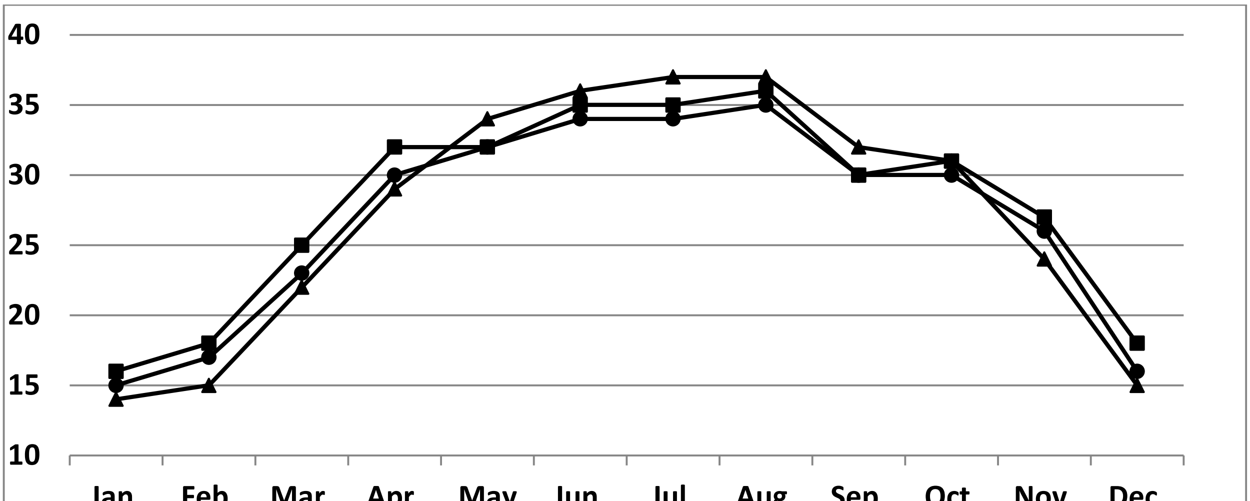

Fig. 3. Maximum temperature (°C) under 0, 40, and 60% shading levels

Table 1. Effect of different levels of irrigation and shading on leaves number, leaf area (cm^2), percentage of infected inflorescences by powdery mildew and percentage of malformed inflorescences, initial and final fruit set of 'Keitt' mango trees during 2017 and 2018 seasons

Irrigation levels (F1)	Shading levels (F2)	Leaves number		Leaf area (cm^2)		Powdery mildew infected panicle (%)	
		2017	2018	2017	2018	2017	2018
100% IR		12.6 A	12.6 A	75.7 A	79.8 A	9.44 A	7.78 A
85% IR		12.4 A	12.1 A	77.2 A	80.7 A	5.00 B	5.00 B
70% IR		12.0 A	12.6 A	64.1 B	66.8 B	3.89 B	2.22 C
	60% SH	12.7 A	12.4 AB	72.2 AB	77.4 A	8.33 A	6.11 A
	40% SH	13.0 A	12.8 A	74.7 A	77.8 A	3.33 B	3.89 A
	0% SH	11.3 B	12.0 B	70.1 B	72.0 B	6.67 A	5.00 A
100% IR +	60% SH	13.7 a	12.7 ab	78.3 ab	78.3 bc	10 a	8.3 a
	40% SH	13.3 a	12.7 ab	77.0 abc	84.3 a	6.7 ab	6.7 ab
	0% SH	10.7 c	12.3 ab	71.7 cd	76.7 cd	11.6 a	8.3 a
85% IR +	60% SH	12.7 ab	12.0 b	76.7 bc	82.3 ab	6.7 ab	6.7 ab
	40% SH	13.0 ab	12.3 ab	83.3 a	82.3 ab	1.6 b	3.3 bc
	0% SH	11.7 bc	12.0 b	71.7 cd	77.3 bc	6.7 ab	5.0 abc
70% IR +	60% SH	11.7 bc	12.7 ab	61.7 e	71.7 de	8.3 a	3.3 bc
	40% SH	12.7 ab	13.3 a	63.7 e	66.7 ef	1.6 b	1.6 c
	0% SH	11.7 bc	11.7 b	67.0 de	62.0 f	1.6 b	1.6 c
		Malformed panicle (%)		Initial fruit set		Final fruit set	
100% IR		13.9 A	13.9 A	4.9 A	4.7 B	2.8 B	2.6 AB
85% IR		10.6 B	10.6 B	5.5 A	5.6 A	3.6 A	3.0 A
70% IR		3.3 C	3.3 C	4.0 B	4.8 B	1.6 C	2.3 B
	60% SH	12.2 A	12.2 A	5.4 A	5.4 A	45.9 B	2.6 B
	40% SH	7.2 B	7.2 B	5.3 A	5.3 A	3.8 A	3.6 A
	0% SH	8.3 B	8.3 B	3.6 B	4.2 B	1.2 C	1.8 C
100% IR +	60% SH	18.3 a	18.3 a	6.3 a	5.0 bc	3.3 ab	2.3 bc
	40% SH	11.7 b	11.7 b	5.0 bc	4.7 bc	4.0 ab	3.3 ab
	0% SH	11.7 b	11.7 b	3.3 d	4.3 cd	1.0 de	2.0 c
85% IR +	60% SH	13.3 b	13.3 b	6.0ab	6.0 a	4.3 a	3.3 ab
	40% SH	6.7 c	6.7 c	6.3 a	6.0 a	4.3 a	4.0 a
	0% SH	11.7 b	11.7 b	4.3 cd	4.7 bc	2.0 cd	1.7 c
70% IR +	60% SH	5.0 cd	5.0 cd	4.0 cd	5.3 ab	1.0 de	2.0 c
	40% SH	3.3 de	3.3 de	4.7 c	5.3 ab	3.0 bc	3.3 ab
	0% SH	1.7 e	1.7 e	3.3d	3.7 d	0.7 e	1.7 c

Values followed by the same letter(s) in each column are not statistically different at 5% level
F1 – factor one (irrigation level), F2 – factor two (shading level)

levels of irrigation or shading (Tab. 1). It was observed that decreasing irrigation level didn't affect leaves number but it significantly decreased leaves area. Based on our results, it was concluded that, under deficit irrigation conditions 'Keitt' mango trees tended to decreased leaf area than decreasing leaves number which may be a mechanism to alleviate drought stress. While the medium irrigation or shading level gave the best results in this respect. For the interaction, 40% SH + 85% IR or 40% SH + 100% IR recorded the highest leaf area in the first and second season, respectively.

Flowering parameters

Powdery mildew infection (%). For the percentage of the infected panicles by powdery mildew (Tab. 1), the data proved that, the highest level of irrigation and shading recorded the highest significant infection compared to the lowest ones. Also, for the interaction, the lowest level of irrigation and shading (70% IR + 0% SH) significantly decreased powdery mildew infection in both seasons compared to the control (100% IR + 0% SH). Heavy shading (60%) or irrigation level (100%) resulted in high relative humidity which permit a suitable environmental condition for fungal diseases.

Malformed panicles (%). The highest level of irrigation and shading (Tab. 1) recorded the highest significant Malformed panicles compared to the lowest ones. Percentage of malformed panicles were decreased gradually with decreasing irrigation level up to 70%, which gave a significant values compared to the control (100% IR). Moreover, 40% SH level decreased the malformed panicles than 60% SH with a significant values in the first season. For the interaction effect, 70% IR + 40% SH or 0% SH and 85% IR + 40% SH recorded the lowest malformed inflorescence compared to the control (100% IR + 0% SH).

Fruiting parameters

Number of initial fruit set. The results (Tab. 1) clear that, either moderate level of irrigation (85%) or shading (40%) recorded the highest significant initial fruit set compared to the other two levels of shading or irrigation. For the interaction effect, 85% IR + 40% SH increased number of initial fruit set significantly compared to the control (100% IR + 0% SH). On the other hand, 70% IR + 0% SH decreased it significantly compared to the control.

Number of final fruit set. Moderate irrigation level (40%) increased final fruit set compared to the other two irrigation levels in both seasons (Tab. 1). Moreover, moderate shading level (40%) increased it significantly compared to the other two shading levels. For the interaction effect, 85% IR + 40% SH increased final fruit set significantly compared to the control (100% IR + 0% SH). While the lowest values recorded by 70% IR + 0% SH as compared to the other treatments.

Fruit sunburn damage (%). Under Egypt conditions, 'Keitt' fruit had a higher incidence of sunburn damage between 36–56% (Tab. 2). Decreasing irrigation level increased sunburn damage as 0% shading level did. Also for the effect of irrigation and shading on sunburn damage, results show that all shading treatments were superior in reducing sunburn damage significantly compared to the other treatments.

Number of fruits/tree. Either moderate level of irrigation (85%) or shading (40%) recorded the highest significant fruit number per tree compared to the lowest levels of irrigation and shading (Tab. 2). For the interaction, the highest number of fruits per tree at harvest was obtained by either 85% IR + 40% SH compared to the other treatments with a significant values compared to the control (100% IR + 0% SH).

Fruit weight (g). The lowest irrigation level recorded the lowest fruit weight with a significant value in 2018 season. While, 40% SH increased fruit weight significant compared to 60% SH (Tab. 2). For the interaction, the lowest significant fruit weight was recorded by 70% IR + 60% SH in both seasons compared to the control (100% IR + 0% SHL).

Yield (kg). Decreasing either irrigation or shading levels significantly decreased the fruit yield (Tab. 2). Since the lowest irrigation or shading recorded the lowest significant yield. Moreover, the highest significant yield was recorded by 85% IR + 40% SH in both seasons beside 100% IR + 40% SH in the first season. Under deficit water irrigation level (70% IR) treatment of 40% SH succeeded in increasing yield by 23.7% and 20.4% compared to the uncovered control in both seasons, respectively.

Water use efficiency WUE (kg m^{-3}). Moderate irrigation level (85%) recorded the highest significant WUE compared to the other two irrigation levels (Tab. 2). Also, 40% SH recorded the highest significant WUE compared to the other two shading levels.

Table 2. Effect of different levels of irrigation and shading on sunburn damage (%), number of fruits/tree, fruit weight (g), yield (kg/tree), leaf chlorophyll content and water use efficiency of 'Keitt' mango trees during 2017 and 2018 seasons

Irrigation levels (F1)	Shading levels (F2)	Sunburn fruit %		Number of fruits/tree		Fruit weight (g)	
		2017	2018	2017	2018	2017	2018
100% IR		12.1 A	14.4 B	21.7 A	18.6 B	682.00 A	638.33 B
85% IR		12.8 A	15.6 AB	23.2 A	21.9 A	644.67 A	714.67 A
70% IR		12.4 A	18.9 A	17.9 B	15.0 C	642.00 A	575.56 C
	60% SH	0.0 B	0.0 B	21.0 B	18.6 AB	617.22 B	610.56 B
	40% SH	0.0 B	0.0 B	22.9 A	20.3 A	672.44 A	696.89 A
	0% SH	37.3 A	48.9 A	18.9 C	16.6 B	679.00 A	621.11 B
100% IR +	60% SH	0.0 b	0.0 c	21.7 bcd	19.7 bc	653.67ab	585.00 e
	40% SH	0.0 b	0.0 c	23.3 ab	20.0 bc	686.00a	706.67 b
	0% SH	36.3 a	43.3 b	20.0 cd	16.0 de	706.33a	623.33 cd
85% IR +	60% SH	0.0 b	0.0 c	22.3 bc	22.0 ab	623.33ab	700.00b
	40% SH	0.0 b	0.0 c	25.7 a	23.7 a	659.00ab	807.33a
	0% SH	38.3 a	46.7 b	21.7 bcd	20.0 bc	651.67ab	636.67c
70% IR +	60% SH	0.0 b	0.0 c	19.0 d	14.0 de	574.67b	546.67f
	40% SH	0.0 b	0.0 c	19.7 cd	17.3 cd	672.33a	576.67e
	0% SH	37.3 a	56.7 a	15.0 e	13.7 e	679.00a	603.33 de
		Yield (kg/tree)		Leaf chlorophyll content (SPAD values)		Water use efficiency (kg/m^3)	
100% IR		14.7 A	11.9 B	50.1 AB	48.7 B	1.12 C	0.91 B
85% IR		14.9 A	15.6 A	50.0 B	50.1 A	1.35 A	1.4 A
70% IR		11.2 B	8.6 C	51.3 A	50.6 A	1.24 B	0.94 B
	60% SH	12.9 B	11.4 B	47.4 C	47.3 C	1.17B	1.03 B
	40% SH	15.2 A	14.4 A	53.7 A	52.6 A	1.39 A	1.3 A
	0% SH	12.7 B	10.1 B	50.3 B	49.4 B	1.15 B	0.92 B
100% IR +	60% SH	14.0 b	11.3 d	45.0 d	44.3 f	1.27 b	0.86 d
	40% SH	16.0 a	14.3 bc	53.3 ab	52.0 b	1.51 a	1.1 c
	0% SH	14.0 b	10.0 de	52.0 b	49.7 cd	1.27 b	0.76 d
85% IR +	60% SH	14.0 b	15.7 b	48.7 c	49.0 de	1.17 bc	1.42 b
	40% SH	16.7 a	19.0 a	54.7 a	54.0 a	1.4 a	1.72 a
	0% SH	14.0 b	12.0 cd	46.7 cd	47.3 e	1.1 bc	1.09 c
70% IR +	60% SH	10.7 c	7.3 f	48.7 c	48.7 de	1.23 bc	0.80 d
	40% SH	13.0 b	10.0 de	53.0 ab	51.7 b	1.07 c	1.1 c
	0% SH	10.0 c	8.3 ef	52.3 b	51.3 bc	0.054 d	0.92 cd

Values followed by the same letter (s) in each column are not statistically different at 5% level
F1 = factor one (irrigation level), F2 = factor two (shading level)

For the interaction effect, 85% IR + 40% SH recorded the highest significant WUE compared to the control (100% IR + 0% SH) in both seasons.

Physiological parameters and water relationships

Leaf chlorophyll concentration. A relative high chlorophyll concentration was recorded at 70% IR compared to the other two irrigation levels. Also, 40% SH recorded the highest chlorophyll content compared to the other shading levels (Tab. 2). 'Keitt' mango grown under medium level of 85% IR + 40% SH gave the highest significant leaf chlorophyll concentration while, the highest level of treatments (100% IR + 60% SH) decreased it significantly. Generally, increasing shading levels more than 40% tended to decrease chlorophyll concentration. Since, 40% recorded the highest value while 60% recorded the lowest one with a significant differences between them. Irrigation had no effect on chlorophyll concentrations.

Proline content. The highest level of irrigation and shading recorded the lowest significant proline content compared to the other irrigation or shading treatments (Tab. 3). For the interaction, 100% IR + 60% SH recorded the lowest significant values compared to the other treatments. The significance increase observed in proline content in 85% IR and 70% IR means it may be suffers from partial water stress. But the interaction between shading and irrigation levels succeeds in alleviating it.

LWC and RWC. LWC and RWC increased gradually either by increasing level of irrigation or shading (Tab. 3). The highest level of both two factors recorded the highest significant values. For the interaction, Also 100% IR + 60% SH recorded the highest LWC

Table 3. Effect of different levels of irrigation and shading on water use efficiency (kg/m^3), leaf proline (µmoles/g), leaf water content (%) and relative water content (%) of 'Keitt' mango trees during 2017 and 2018 seasons

Irrigation levels (F1)	Shading levels (F2)	Leaf proline (µmoles/g)		Leaf water content (%)		Relative water content (%)	
		2017	2018	2017	2018	2017	2018
100% IR		0.0195 B	0.0195 B	69.6 A	72.3 A	80.7 A	84.3 A
85% IR		0.0287 A	0.0282 A	68.3 B	71.3 B	79.7 B	82.3 B
70% IR		0.0283 A	0.0288 A	65.7 C	70.0 C	77.7 C	80.0 C
	60% SH	0.0195 B	0.0194 B	70.0 A	74.0 A	81.3 A	84.3 A
	40% SH	0.0286 A	0.0285 A	67.6 B	70.7 B	79.7 B	82.0 B
	0% SH	0.0285 A	0.0194 B	66.0 C	69.0 C	77.0 C	80.3 C
100% IR +	60% SH	0.0161c	0.0164c	72.0 a	75.0 a	82.0 a	87.0 a
	40% SH	0.0208b	0.0200b	68.7 bc	72.0 cd	81.0 ab	84.0 b
	0% SH	0.0215b	0.0217b	68.0 cd	68.0 cd	79.0 cd	82.0 c
85% IR +	60% SH	0.0213b	0.0209b	70.0 b	74.0 ab	82.0 a	84.0 b
	40% SH	0.0341a	0.0337a	68.0 cd	71.0 de	80.0 bc	82.0 c
	0% SH	0.0305a	0.0309a	67.0 de	67.0 de	77.0 e	81.0 cd
70% IR +	60% SH	0.0212b	0.0212b	68.0 cd	73.0 ef	80.0 bc	82.0 c
	40% SH	0.0313a	0.0311a	66.0 e	69.0 fg	78.0 de	80.0 d
	0% SH	0.0330a	0.0338a	63.0 f	63.0 f	75.0 f	78.0 e

Values followed by the same letter (s) in each column are not statistically different at 5% level
F1 = factor one (irrigation level), F2 = factor two (shading level)

and RWC values followed by 85% IR + 60 SH. While the lowest values recorded by 70% IR + 0% SH.

DISCUSSION

For the effect of irrigation on 'Keitt' mango, the results proved that, decreasing irrigation levels decreased final fruit set, number of fruit per tree and fruit yield. The data confirmed previously by Léchaudel and Joas [2007] as they found that increasing mango fruit drop from partial root zone drying resulted in decreasing number of fruits. In addition, Spreer et al. [2007] who reported that, at early stage of fruit growth water deficit increased fruit drop in 'Chok Anan' mango. This might be resulted from production of ABA as a hormonal signal from plant roots to the shoot for reducing stomatal aperture [Hartung et al. 2002] and involved in fruit. Also, it had a detrimental effect on pollination and fruit set [Lu and Chacko 1997], reducing mango fruit growth [Simmons et al. 1995] and reducing mango fruit weight [Bithell et al. 2010].

The results refer to that, reducing irrigation level up to 85% had a good effect on yield similar to 100% IR with no significant differences. In China, Wei et al. [2017] observed that irrigation 'Guifei' mango trees at medium irrigation level (65–70%) of field capacity recorded the highest fruit yield compared to high (79–82%) irrigation level. The same results reported by Mthembu [2001] on 'Kent' mango trees and Nasir and Mian [1993] on 'Samar Bahisht Chaunsa' mango trees. Increasing yield under moderate irrigation may be occurred due to higher crop load rather than larger fruit size [Pavel and de Villiers 2004, Spreer et al. 2006].

Concerning the effect of shading on modification of microclimate (Figures 1, 2 and 3) was reported previously, an increase in RH by 13–25% [Wachsmann et al. 2014] and by 3.24–12.9% [Mditshwa et al. 2019] under white shade nets. These findings may be attributed to lower wind speed under shad nets beside lower excessive solar radiation [Tanny et al. 2006, Abul-Soud et al. 2014, Medrano et al. 2015]. Also, shading had a great role in reduction of heat stress, soil surface temperature, leaf temperature, rind temperature and fruit temperature during summer [Meena et al. 2016]. Which improved flowering intensity, fruit set and yield [Nissim-Levi et al. 2008] resulting from decreasing fruitlet abscission risk or fruit drop [Mditshwa et al. 2019]. Increasing yield under shading was reported by several authors with mango in subtropical region such as Egypt [Medany et al. 2009], Israel [Nissim-Levi et al. 2008]. Moreover, in South Africa Mthembu [2001] found that light shading (20%) for 'Kent' mango increased yield and fruit number while heavier shading (50%) decreased it.

The positive effects of shading under excessive solar radiation on fruit yield could be referred to five reasons. First, shading can modified microclimate which alleviate water and heat stress specially during a critical stage like mid-day, flowering and fruit set period. Second, shading had a great role on physiological parameter Since chlorophyll content affected mainly by light supply which shading density controlled in. Under uncovered excessive solar irradiation led to reduce the efficiency of plastids [Pattanayak et al. 2005], reduce photosynthesis through metabolic impairment [Montanaro et al. 2009], cause a higher degree of photo inhibition [Kamaluddin and Grace 1992, Jutamanee and Onnom 2016]. While, moderate shading maintaining high photosynthetic of 'Nam Dok Mai' mango [Jutamanee and Onnom 2016] due to shaded leaves contain a greater extent photosynthetic pigments [Suzuki and Shioi 2003], decrease leaf temperature by 1.83–3.33°C [Incesu et al. 2016] and decrease canopy temperature by 1–4% [Jifon and Syvertsen 2003]. On the other hand, heavy shad net intensity resulted in a reduction of photosynthesis [Middleton and McWaters 2002, Amarante et al 2011]. Third, shading had a great role on protecting fruits from direct incident radiation and prevent the increase in fruit temperature [Dussi et al. 2005, Iglesias and Alegre 2006] which decreased fruit sunburn damage [Andrews and Johonson 1996, Dussi et al. 2005, Gindaba and Wand 2007, Amarante et al. 2009]. Shading material was superior than covering the fruit by papers due to long live, more fixed and preserve fruit surface from excessive humidity [Mditshwa et al. 2019].

On the other hand, heavy shading can reduce fruit yield of 'Primosole' mandarins [Germana et al. 2003] grown under dark colored nets (50% grey and 67 black nets), mandarin Wachsmann et al. [2014], due to lower photosynthesis. Moreover, heavy shading in this study increase powdery mildew infection and malformation due to increasing relative humidity and decrease the maximum temperature which is necessary for the infection [Joubert et al. 1993, Schoeman et al. 1995, Chakrabarti et al. 1998, Elad et al. 2007, Atinksky 2009]. Finally we can concluded that, effects of shading on fruit yield may be depended on the quantity of solar radiation (location) and shad net density. In subtropical regions, under higher excessive solar radiation and temperature, light and moderate shad density increased yield such as South Africa [Mthembu 2001, Blakey et al. 2016], India [Kashyap et al. 2012] and Egypt [Medany et al. 2009]. While, in temperate regions under moderate solar radiation and temperature, light shading only may be productive or may be reduced yield such as [Jackson et al. 1977] and USA [Miller et al. 2015].

Fifth, shading increased WUE, in this regard, Nicolas et al. [2005] found that under un-shaded apricot trees high radiation and soil water deficit led to plant tissue dehydration [Hsiao 1990], transpiration rate surpassed the roots ability to supply water and temperature stress, which a ltering gas exchange, stomatal conductance and CO_2 assimilation [Barron-Gafford et al. 2007]. Similar results were reported on lemon [Alarcon et al. 2006, Nicolas et al. 2008], citrus [Jifon and Syvertsen 2003] and mango [Jutamanee and Onnom 2016].

Under shading conditions where there are relative low solar radiations, plant transpiration and soil evaporation. Consequently, less irrigation requirements expected under shad net, which is suitable for fruit production under water shortage. The most appropriate accumulative effects of irrigation and shading were achieved under moderate level SH (40%) and IR (85%). Increasing yield and WUE were resulted from significantly increase of leaf area, leaf water content, leaf chlorophyll content, fruit set, fruit numbers per tree beside decreasing sunburn damage, powdery mildew infection. Trees growing under nets might have a more water efficiency as a result of lower leaf transpiration rate [Ebert and Casierra 2000], lower leaf temperature [García-Sánchez et al. 2015, Incesu et al. 2016], suitable plant water content (LWC and RWC), lower soil temperature and the water loss by evaporation [Chen et al. 2007]. Similar results were reported on lemon [Alarcon et al. 2006], citrus [Jifon and Syvertsen 2003] and mango [Jutamanee and Onnom 2016]. Also, shade nets create a conducive IR and soil environment around the root system, which promote nutrient absorption [Abul-Soud et al. 2014]. On the other hand the highest level of irrigation and shading together (100% IR + 60% SH) decreased chlorophyll content, leaf area final fruit set. Also, they increased powdery mildew infection and malformed panicle percent subsequently it decreased fruit yield and water use efficiency compared to moderate irrigation and shading level (85% IR + 40% SH).

CONCLUSION

Under excessive solar radiation, irrigation water scarcity (70%) had a bad effect on growth, fruiting and yield of 'Keitt' mango trees. While, moderate shading level (40% SH) not only reduced water stress, fruit sunburn damage or powdery mildew infection but also it increased leaf area, chlorophyll concentration, water use efficiency, relative water content, leaf water content, fruit set which improve fruiting and yield of 'Keitt' mango trees.

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Units – the international SI system is binding, g, Kg, SPAD (chlorophyll), Celsius degree (°C), relative humidity (%), leaf area (cm^2), proline µmoles/g.

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