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ORIGINAL PAPER

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# MITIGATION OF HEAT STRESS EFFECTS BY USING SHADE NET ON WASHINGTON NAVEL ORANGE TREES GROWN IN AL-NUBARIA REGION, EGYPT

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## ABSTRACT

High temperature stress can be detrimental to plants, resulting in reduced fruit yield and increased incidences of fruit disorders. One strategy that farmers can use to maintain or increase their yields in the face of a changing climate is to adjust of farm climate by using shade net on the trees. Such, the use of shade netting on Washington navel orange planted on the sandy soil in Al-Nubaria region, Egypt were studied during two successive seasons, either using a permanent shade throughout all the season or using a moveable shade for certain period from the first of March until the end of June for every season. Growth (No. of shoots/one meter branch, No. of leaves/shoot, shoot length and chlorophyll content of the leaves, leaf area and tree canopy), macronutrients (N, P, K, Ca, Mg) and micronutrients (Fe, Zn, Mn, Cu, Na) content in the leaves, fruit characteristics (number, weight, diameter, peel thickness, total soluble solids, total acidity and ascorbic acid), yield and crop efficiency, were determined. It can be concluded that covering Washington navel orange trees grown on sandy soil with shade net especial covering the trees for certain period was very effective at protecting orange trees and led to improve the growth, increase the yield and maintain fruit quality.

**Key words:** navel orange, shade net, growth, nutrients status, yield, fruit quality, crop efficiency

## INTRODUCTION

High temperature stress can be detrimental to plants, resulting in reduced fruit yield and increased incidences of fruit disorders.

Washington navel orange ranks the top among orange cultivars and it has a great importance in the local and export markets. The researchers who worked in the national campaign for improving citrus productivity in Egypt observed that its yield is still low, especially those are grown on reclaimed or sandy lands of low native fertility and low nutrient and water holding capacities with change of temperature. This increase the probability that fruit set will highly reduce and also, the period following fruit set is very critical and sensitive to warm-dry atmosphere; this period lasts until the end of June drop in Egypt. The tropical fruit trees need an appropriate micro-climate during all its phenological phases, modification of it by using shade net is necessary at least during part of spring going through summer [Medany et al. 2009].

One strategy that farmers can use to maintain or increase their yields in the face of a changing climate is to adjust farm climate by using shading with nets on

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the trees. Mahmood et al. [2018] reported in their paper to review recent advances regarding those effects that shading and screens are efficient tools for crop production in adverse climatic and environmental condition, which reduce solar radiation, air velocity, air temperature and evapotranspiration and increase air relative humidity and thus may strongly influence production and quality. So, Takeda and Veazie [2009] showed that the Mediterranean region lead in protected environment agriculture, and this may alter phytochemical of fruits and vegetables. Wien [2009] found that, although covering with clear polyethylene is used principally to produce annual crops such as vegetables and cut flowers, increasing interest has focused on their use for perennial crops. Jutamanee and Ommon [2016] claimed that excess solar radiation under hot climate can lead to decline the photosynthetic activity with detrimental effects on growth and yield of mango and shading the trees can be an effective technique to avoid undesirable effects of excess solar under hot climate. Jifon and Syvertsen [2001] reported that exposing citrus trees to high solar irradiation and high temperature may result in reduced growth, fruit yield and fruit quality. Thus, Zhou et al. [2018] optimized the use of photoselective nets in citrus orchard in semi-arid areas to ensure an efficient balance between above and below-ground plant growth.

The experiment was designed to evaluate covering Washington navel orange trees with shade netting, which may overcome the unsuitable environmental conditions to produce Washington navel orange without affecting yield and quality characteristics. Since, increasing usage of shade net is a major goal in modern agriculture to maintain food security and agriculture sustainability.

## MATERIALS AND METHODS

Washington navel orange (*Citrus sinensis* L. Osbeck) trees, grafted on volkamer lemon rootstock (*C. volkameriana* L.), were about 12 years old, on healthy and uniform condition, planted in a system of 3.5 × 5 m, and grown on sandy soil in the National Research Centre farm for research and production in Al Emam Malek Village, Al Nubaria region, Al Behira Governorate, Egypt.

Shade is manufactured from knitted polyethylene fabric that does not rot, mildew or become brittle; its diameter was 0.28 mm and cell size was 3 × 7.4 mm, from Al-Amir Shade Net Company, El-Gharbia Governorate. It can be used for canopies and farm stands. Shade netting is an architectural structure, made from intersecting pieces of (Casuarina columns). The first step to create structure for the shading net was done by digging holes, placing Casuarina columns with 5-meters high, then the wire was tightened on them, then covered with the white net (about 25% shading) on all sides and horizontally above the trees which it was rolled up to a height of 4 m to improve ventilation. The use of shade netting was either as a permanent shade through all the seasons (over the years) in 2017 and 2018 or as a moveable shade for certain period from the first of March "the beginning of flowering" until the end of June "after the fall of June" for each season (from March 2017 to June 2017, then from March 2018 to June 2018) then, the shade has been fold after the end of the fall of June comparing with the unshading trees (control). The other horticultural practices were similar for all trees and also as recommended from national campaign for improving citrus productivity in Egypt. Drip irrigation system was installed to irrigate all trees. The experiment was set in a completely randomized blocks design. Each treatment and block consisted of 6 rows of 12 trees. Three trees per treatment were selected from the central row of each block. Soil sample was analyzed at the beginning of the work for texture, pH and electrical conductivity (EC) using water extract (1 : 2.5) method, for total calcium carbonate ($CaCo_3$%); calcimeter method and for organic matter (OM %), potassium dichromate was used [Chapman and Pratt 1978]. Phosphorus was extracted using sodium bicarbonate [Olsen et al. 1954]. Potassium (K), calcium (Ca), magnesium (Mg) and sodium (Na) were extracted using ammonium acetate [Jackson 1973]. Iron (Fe), manganese (Mn), zinc (Zn) and copper (Cu) were extracted using DPTA [Lindsay and Norvell 1978]. Table 1 shown physical and chemical properties of the experimental soil.

The climate data for the Al-Nubaria region were collected from November 2016 to June 2017 and from November 2017 to June 2018. They include (degree of solar radiation, upper and lower temperature, wind speed, dew/frost point temperature, relative humidity) in Table 2.

**Table 1.** Physical and chemical properties of the experimental soil

| Parameter | Value | Parameter | Value |
|---|---|---|---|
| Sand (%) | 92.6 | Ca (mg/100 g) | 286 |
| Clay (%) | 4.6 | Mg (mg/100 g) | 29.2 |
| Silt (%) | 2.8 | Na (mg/100 g) | 29.6 |
| Texture | Sandy | K (mg/100 g) | 9.34 |
| EC (ds/m) | 0.41 | $CaCO_3$ (%) | 1.2 |
| pH | 8.25 | Fe (mg/kg) | 16.4 |
| OM % | 0.48 | Mn (mg/kg) | 4.8 |
| Total N (mg/100 g) | 14.8 | Zn (mg/kg) | 0.9 |
| Available P (mg/100 g) | 1.56 | Cu (mg/kg) | 0.4 |

EC – electrical conductivity, OM – organic matter

**Table 2.** Climate of Egypt, Al-Nubaria monthly, in the seasons 2016/2017 and 2017/2018

| Season | Date | SRAD ($MJ/m^2$/day) | $T_{max}$ (°C) | $T_{min}$ (°C) | WIND (m/s) | $T_{dew}$ (°C) | RH (%) |
|---|---|---|---|---|---|---|---|
| 2016/2017 | Nov. 2016 | 13.65 | 24.01 | 14.21 | 4.08 | 10.90 | 61.86 |
| | Dec. 2016 | 11.85 | 17.90 | 8.52 | 4.43 | 5.80 | 63.10 |
| | Jan. 2017 | 12.55 | 16.82 | 6.05 | 3.93 | 3.64 | 62.92 |
| | Feb. 2017 | 15.65 | 18.90 | 6.89 | 3.70 | 5.28 | 63.04 |
| | Mar. 2017 | 20.30 | 22.64 | 9.85 | 4.54 | 6.37 | 55.41 |
| | Apr. 2017 | 24.22 | 26.98 | 12.01 | 4.34 | 7.21 | 47.68 |
| | May 2017 | 27.37 | 31.81 | 16.30 | 4.52 | 10.15 | 43.95 |
| | Jun. 2017 | 29.87 | 34.88 | 19.54 | 4.44 | 13.49 | 44.77 |
| 2017/2018 | Nov. 2017 | 18.7 | 24.54 | 12.30 | 0.18 | 9.14 | 76.03 |
| | Dec. 2017 | 17.11 | 21.94 | 10.97 | 0.21 | 7.91 | 84.48 |
| | Jan. 2018 | 15.91 | 19.35 | 8.69 | 0.54 | 5.34 | 78.00 |
| | Feb. 2018 | 17.98 | 23.06 | 10.79 | 0.29 | 5.06 | 75.43 |
| | Mar. 2018 | 21.94 | 26.84 | 11.67 | 0.45 | 2.84 | 63.94 |
| | Apr. 2018 | 24.53 | 28.61 | 13.96 | 0.45 | 5.60 | 63.53 |
| | May 2018 | 26.22 | 32.61 | 18.65 | 0.53 | 9.20 | 60.16 |
| | Jun. 2018 | 25.50 | 34.16 | 20.51 | 0.48 | 11.74 | 61.53 |

SRAD – solar radiation, $T_{max}$ – maximum air temperature, $T_{min}$ – minimum air temperature, WIND – wind speed, TDEW – dew/frost point temperature, RH – average relative humidity

### Measurements

**Growth and yields.** In early September, leaf area was measured using the formula of 0.608 constant × (maximum leaf length × maximum leaf breadth) according to Shrestha and Balakrishnan [1985]. Number of shoots/one-meter branch, number of leaves/shoot and shoot length were measured. Chlorophyll content was determined as CCI (chlorophyll content index) using Chlorophyll Content Meter 003109 (CCM-200 plus, Opti-Sciences). At commercial harvest (colour break) in early December, yield as weight and number of fruits per tree were recorded. Canopy volume of trees was measured in early December which tree shape was considered as a one-half of a probate sphere (volume = 4/6 × π × height × radius2, π = 22/7) as described by Roose et al. [1989]. Cropping efficiency was calculated by dividing the fruit yield weight by the canopy volume according to Whitney et al. [1995].

**Leaf mineral composition.** Leaf samples were collected in early September and were mature fully expand from non fruiting non flushing spring cycle growth (5 old month) according to Jones and Embleton [1960], then washed, dried at 70°C until a constant weight, ground and digested using an acid mixture consisting of nitric, perchloric and sulfuric acids in the ratio of 8 : 1 : 1 (v/v), respectively according to Chapman and Pratt [1978]. Nitrogen was measured by semi-micro Kjeldahl method of Plummer [1978]. Phosphorus was determined using a spectrophotometer at 882-OVV by the method outlined by Jackson [1973]. Potassium, calcium and sodium were determined by a flame photometer Jenway PFP7. Magnesium, iron, manganese, zinc and copper were determined using atomic absorption spectrophotometer Perkin Elmer 1100 [Cottanie et al. 1982]. These measurements were performed in the Agricultural Services Unit and Laboratory Analysis of Research Project (Micronutrients and Other Plant Nutrition Problems in Egypt) in NRC.

**Fruit quality.** Ten fruits were randomly sampled per each tree for determination of weight, diameter, peel thickness, then from the juice, total soluble solids percentage (TSS Brix %) determined by Carl Zeiss hand refractometer; total acidity as anhydrous citric acid % and vitamin C. The latter was expressed as mg ascorbic acid per 100 ml juice according to AOAC [1995].

**Statistical analysis.** The data obtained in each season were analyzed by ANOVA according to Snedecor and Cochran [1982]. Means were separated by Duncan [1955] and multiple range test using a significance level of $P < 0.05$.

## RESULTS AND DISCUSSION

Results presented in (Fig. 1) indicates that number of shoots /one meter branch was greater under the use of tree cover with shade nets for a specified period of time, whereas the number of leaves produced on trees was higher under tree coverage with shade net throughout the season. There are no significant differences in the shoot length and the area of the developing leaf and its total chlorophyll content during the two seasons for all trees of the experiment, except for the shoot length in the first season and also the chlorophyll content of the leaf in the second season were significantly lower with the covered trees for a specified period of time compared with the covered trees over the season and those of uncovered trees. Climatic elements (sunlight, temperature and humidity) considered as crucial factors for cultivation especially for fruit trees such as citrus which have specific environmental requirements and any changes in these climate elements will be reflected on the interaction between climate – soil – water – plant and consequently on response of vegetative growth and fruiting. In this regard, Ilić and Fallik [2017] concluded that with spectra created by different coloured nets, that various plant species respond differently to growth and development, and also that the extent of reduction of chlorophyll content after storage depends on the species, variety and temperature, as accumulation of phytochemicals during the production of plants depends on many factors such as light quantity and quality, type of varieties or cultivars, growing season and metabolic factors. Israeli et al. [1995] indicated that limiting photosynthetic activity might be of crucial importance for banana in the subtropics where temperature may also play an important role, while in the tropics, light may be the main limiting factor. Mata and Botto [2009] show that light quality manipulation is an effective alternative to the application of plant growth regulators in commercial production systems. Improved tree growth under shading might be attributed to the increase of tree ability to uptake water and nutrients which consequently accelerated its vegetative growth rate. Marouelli and Silva [2005] and also

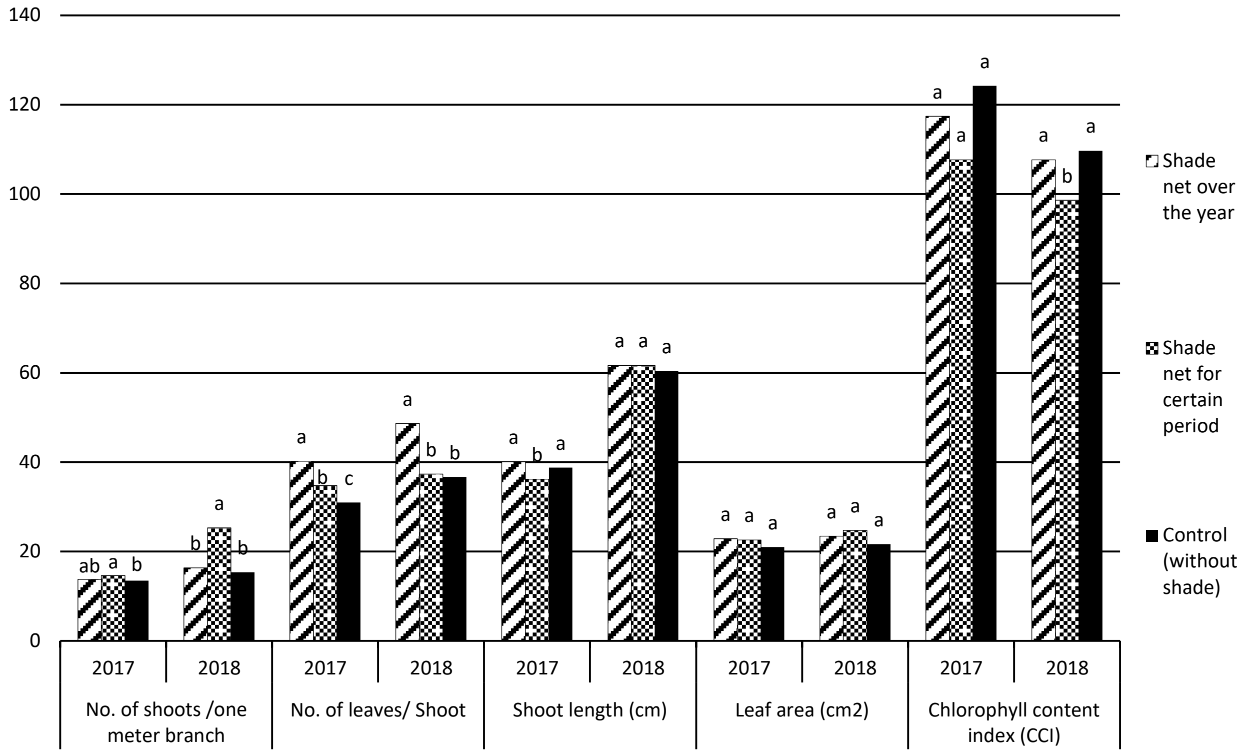


**Fig. 1.** Mitigation of heat stress effects by using shade net on vegetative growth characteristics and chlorophyll content of Washington navel orange trees during 2017 and 2018 seasons. Means followed by the same letter(-s) over each column didn't significantly differ at 5% level

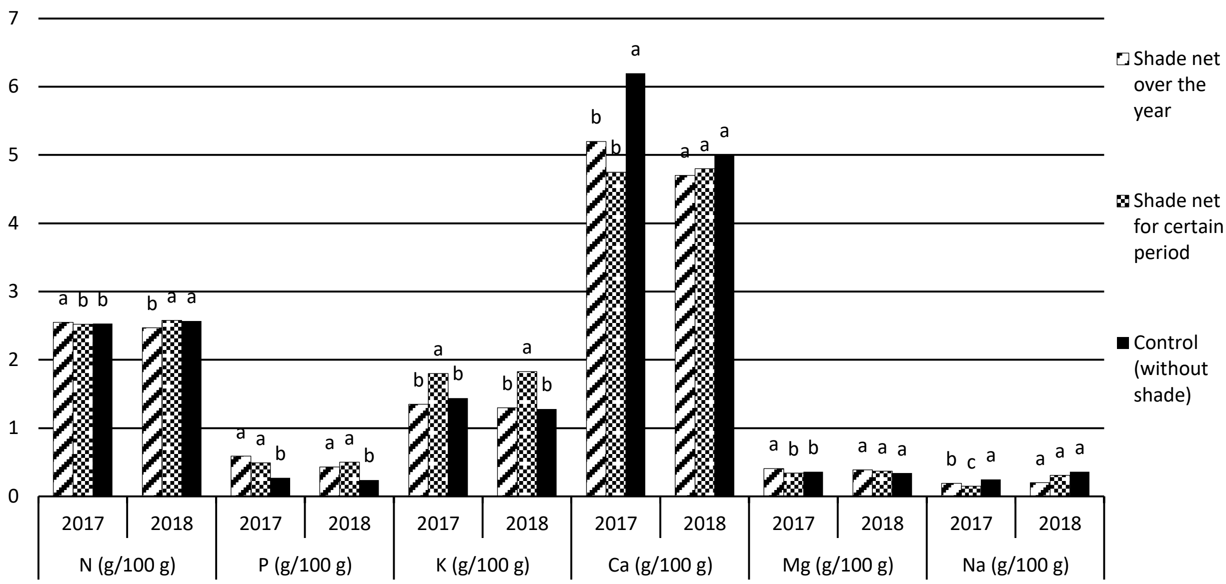


**Fig. 2.** Effect of shade net on Washington navel orange some leaf minerals content during 2017 and 2018 seasons. Means followed by the same letter(-s) over each column didn't significantly differ at 5% level

Jutamanee and Ommon [2016] indicated that shading mango trees can be an effective technique to avoid undesirable effects of excess solar irradiation under hot climate. Gent [2007] and Ilić and Fallik [2017] found that leaf area tends to increase under low light conditions, and shading may result in better coverage of the fruits by leaves. These findings are in harmony with those mentioned by Léchaudel et al. [2002] who reported that growth performance of mango trees and fruit size (based on accumulation of water and dry matter) mainly depend on environmental conditions. Thus, Zhou et al. [2018] observed faster vegetative growth induced by netting treatments, as that, photosynthesis and stomata conductance were affected differently between annual seasons over treatments.

From (Fig. 2) we can observe that all the major elements in the leaf of all the trees under the experiment were within the appropriate limits for the formation of healthy developing citrus leaf according to Werner [1992], who noted that adequate ranges for citrus leaf as percentage were: 2.4–3.5 (N), 0.15–0.3 (P), 1.2–2.0 (K), 3–7 (Ca), 0.25–0.7 (Mg), except that the phosphorus was higher than those limits under all the types of coverage. The results showed that the leaves produced and developing under the conditions of continuous coverage "throughout the season" with shade net contained high phosphorus while the other elements were different. Nitrogen and magnesium were high at leaves growing under tree cover continuously in the first season only. Potassium was increased in leaves growing under tree cover for a certain period of the season. While calcium content of leaves of trees under both the coverage with shade net was less compared to those developing in the control trees in the first season. It was also found that there is no significant difference in calcium, magnesium and sodium contents in leaves of trees in the experiment in the second season. In general, leaf mineral content depends on water and minerals uptake. Shading technology on some locations confirmed a general decrease of maximum daily temperature ($T_{max}$) by 1–5°C, followed by an increase in maximum daily relative air humidity by approximately 3–10% [Ignasi and Alegre 2006]. So, shade altered sunlight intensity with relatively little effect on air temperature.

Based on results presented in (Fig. 3), it was found that all the micro elements in the leaf of all the trees under the experiment were within the standards appropriate limits of the developing healthy citrus leaf according to Wutscher and Smith [1994], who noted that adequate ranges for citrus leaf as ppm are 35–135 (Fe), 19–50 (Zn), 19–100 (Mn), 5–15 (Cu) with some variation among zinc level was less under the use shade net of the cover of the trees, especially the coverage for a limited period. The results showed that growing trees without net cover resulted higher iron, zinc and copper contents than those under both coverage species with shade net. Also, tree leaf under constant coverage with shade net throughout the season contained high iron and manganese in the second season. Moreover, there is reduction of some nutrients in response to some shading treatments may be due to the increase in growth which depletes more amounts of those nutrients, besides, there are an increase in some other elements due to the availability of elements which slow release matches uptake by plant roots and prevents it from leaching. Here from Table 1, it can be noticed that soil texture is sandy, it's known that coarse textured soil lacks both nutrient and water holding capacities. Also, under high soil pH value, availability of some nutrients is expected to be low, EC and almost elements were in the medium level and soil organic matter is used as an indicator of soil fertility. Also, this difference in the uptake of nutrients may be attributed to variation in the breakdown of some elements with time which may alter metal availability for crops. [Alloway and Jackson 1991]. These results are in agreement with those reported by Espinoza et al. [1998].

Table 3 shows that the use of the certain period coverage with shade net resulted in a higher number of fruits per tree, and the use of both covering methods with shade net gave the fruits more weight compared to growing trees without net cover where those had weight similar significant. This was true in both of the seasons. Thus, the yield was higher, especially the yield of the trees covered with shade net for a specific period followed by continuous tree cover compared to growing trees without net cover. In addition, it was also found that the size of the tree (tree canopy) was high under cover use with shade net; in the first season under continuous coverage and in the second season under cover for a limited period of time. The crop efficiency (fruit production per unit of canopy volume) was high under tree cover for a specific period of time followed

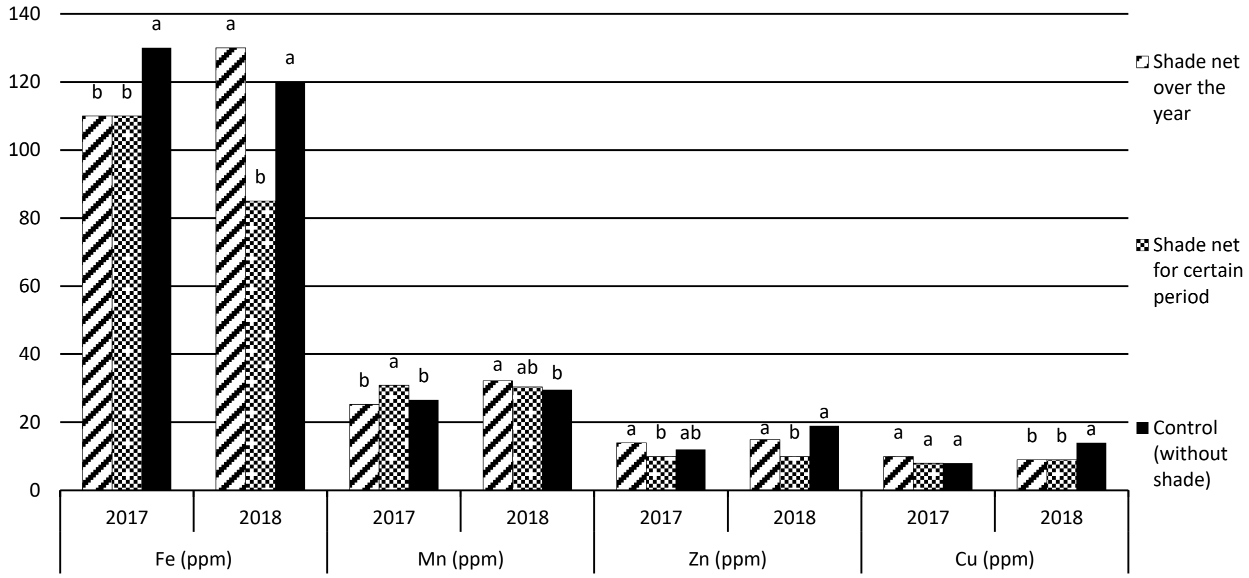


**Fig. 3.** Effect of shade net on Washington navel orange some leaf minerals content during 2017 and 2018 seasons. Means followed by the same letter(-s) over each column didn't significantly differ at 5% level

**Table 3.** Mitigation of heat stress effects by using shade net on yield and its components of Washington navel orange trees during 2017 and 2018 seasons

| Treatment | Number of fruits (No.) | | Fruit weight (g) | | Yield (kg/tree) | | Tree canopy ($m^3$) | | Crop efficiency ($kg/m^3$) | |
|---|---|---|---|---|---|---|---|---|---|---|
| Season | 2017 | 2018 | 2017 | 2018 | 2017 | 2018 | 2017 | 2018 | 2017 | 2018 |
| Shade net Over the year | 140.6 b | 160.0 b | 369.1 a | 387.3 a | 51.89 ab | 61.97 a | 64.54 a | 60.29 b | 0.804 b | 1.027 a |
| Shade net for certain period | 159.0 a | 184.0 a | 359.7 a | 370.0 a | 57.20 a | 68.08 a | 41.06 b | 66.33 a | 1.393 a | 1.026 a |
| Control (without shade) | 142.3 b | 121.0 c | 318.3 b | 343.7 b | 45.29 b | 41.58 b | 47.36 b | 48.70 c | 0.956 b | 0.853 b |

Means followed by the same letter(-s) within each column didn't significantly differ at 5% level by continuous tree cover compared to growing trees without net cover. Shading net resulted in better tree nutrient uptake, higher rates of photosynthesis which might reflect on a greater number of fruits and higher fruit weight [Ngouajio et al. 2007]. Shading gave yield increment when compared with unshaded production due to the increase of the average single fruit weight [Rylski and Spigelman 1986]. So, any effects of shade on yield and fruit quality were likely attributable to the response to irradiance rather than to temperature. This led to increase flower number per plant, fruit set and yield [Gent 2007]. On the other hand, Storey and Treeby [1999] found that the diurnal growth rhythms of fruit from mature trees were insensitive to ambient temperature maxima. In addition, Krizek et al. [2006] show that tomato fruits from plants grown under selective ultraviolet film type had a more weight correspond fruit grown under commercial field. Such, increase in tree canopy is important because the largest trees usually used the most water and results in highest fruit yield [Syvertsen and Smith 1996]. These results are in agreement with those reported by Abd El-Naby et al. [2004] and Abd El-Naby and El-Sonbaty [2016]. On the other hand, the increase in fruit weight by using shade net could not be expected to cause an increase in its diameter as noted with Mata and Botto [2009] which show that light quality manipulation is an effective alternative of the application of plant growth regulators in commercial production systems. Farag and Nagy [2012] found that Washington navel oranges tended to be more elongated in shape with GA alone while they had more round shape with the application of NAA or MCP. in addition, that cavity of navel may be reflected on the incidence this case.

The results in Table 4 showed that there were no significant differences in all studied characteristics of the quality of orange fruits resulting from any of the coverage with net or without net, except for acidity in the first season only, was less with the fruit growing under coverage with net for a specific period compared to the permanent cover or the open field. This was true in both of the seasons. Under covering with shade net either all the year or for certain period, citrus trees have been protected from undesirable effects of high temperature and wind from the first of March to the end of June on number and weight of fruits and the yield. Such, Dayioglu and Hepaksoy [2016] observed that using shade net was without negative impact on fruit quality and maturation. Ilić and Fallik [2017] found that netting have been shown to influence the retention of sensory qualities at harvest, as that there were no significant differences in total soluble solids in fruit harvested under different coloured shade nets.

On the other hand, Marsh et al. [1999] reported that sugar and acid concentrations in fruit from warmed tree were greater than those in fruit grown under ambient conditions. Hence, raising temperatures during early fruit growth increases water uptake into fruit.

**Table 4.** Mitigation of heat stress effects by using shade net on fruit quality characteristics of Washington navel orange during 2017 and 2018 seasons

| Treatment | Fruit diameter (cm) | | Peel thickness (cm) | | Total soluble solids (%) | | Titratable acidity (%) | | Ascorbic acid (mg/100 ml juice) | |
|---|---|---|---|---|---|---|---|---|---|---|
| Season | 2017 | 2018 | 2017 | 2018 | 2017 | 2018 | 2017 | 2018 | 2017 | 2018 |
| Shade net over the year | 8.73 a | 8.66 a | 0.591 a | 0.520 a | 10.36 a | 10.26 a | 1.352 a | 1.033 a | 49.70 a | 41.81 a |
| Shade net for certain period | 8.70 a | 8.85 a | 0.658 a | 0.593 a | 9.75 a | 10.50a | 1.091 b | 1.367 a | 36.68 a | 44.63 a |
| Control (without shade) | 8.36 a | 8.33 a | 0.475 a | 0.520 a | 10.73 a | 10.93a | 1.208 ab | 1.467 a | 48.00 a | 48.21 a |

Means followed by the same letter(-s) within each column didn't significantly differ at 5% level

## CONCLUSIONS

One of the available methods to alleviate the heat stress is shading with net, which used to modify the crop microenvironment to improve plant growth and yield. Netting is frequently used to protect agricultural crops from excessive solar radiation, improving the temperature conditions. Also, resulted in less disorders of fruit crops.

We can conclude that the use of shade net, especially covering the trees for certain period from the first of March until the end of June for every season was very effective at protecting orange trees and maintain the fruit quality. This may be due to the effect of nets on radiation, humidity, evapotranspiration and temperature.

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