IMPACT OF REGULATED DEFICIT IRRIGATION AND FOLIAR ZINC NANOPARTICLES APPLICATION ON PRODUCTIVITY OF MANGO TREES

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ABSTRACT: what is impact of regulated deficit irrigation and foliar Zn nanoparticles application on productivity of mango trees? the answer to this question represents the main objective of this study. To verify this, an experiment was performed during the 2016/2017 on the mango trees mango (Mangifera indica L.) cvs. “Nawomy” and “Sokary” which have about 16 years old in sandy soil under drip irrigation system. 100, 50, 75% of the crop evapotranspiration "ETc" were used, in parallel with three levels of concentrations of NPs-Zn micronutrient (0, 50, and 100 ppm) were applied three times; i.e., before flowering, 10 days after full bloom and after fruit set stages in both seasons. The highest yield and water-use efficiency were obtained with applying the RDI-75% of ETo treatment without significant difference that 100% of ETo treatment. The average fruit weight and size, length and width were larger for mango fruits from the 100% of ETc and 75% of ETc, with TSS%, total reducing sugars and ascorbic acid content being significantly greater than fruits of other irrigation treatments. Therefore, using the nano zinc as foliar sprays on mango trees at a concentration of 100 ppm improved fruit set percentage, total yield fruit quality (physical and chemical properties), also increased water use efficiency. It could be concluded that irrigated trees with 75% of ETc plus foliar spraying of nano zinc (NPs-ZnSO4) at 100 ppm was the most effective treatment for increasing fruit set, total yield and quality as well as water use efficiency of Nawomy and Sokary mango trees.

Key words: Mango, regulated deficit irrigation (RDI), Zn nano-particles, fruit quality and water use efficiency.

INTRODUCTION

Mango (Mangifera indica L.) belonging to family Anacardiaceae is one of most important strategic fruit crops and is a source of hard currency in Egypt. Egypt ranks the seventh after India, China, Thailand, Indonesia, Mexico and Pakistan in the world production of mango, which is estimated at 47.13 million tons according to the Food and Agriculture Organization (FAO) of the United Nations (FAOSTAT, 2017). FAO report also showed that average growth rate of mango production in the country had been 3.76 per cent until 2007 from its production at 2016.

Cultivation of mango trees face factors that limit production in the newly reclaimed soils in the Mediterranean basin of Egypt, especially in North Sinai region. The major problem is the scarcity of rainfall or it irregularity (IPCC, 2000) and deficit of fresh water availability for agricultural is the most pervasive impact environmental stress on mango productivity which limits the sustainable development under climatic changes with population growth (Shangguan et al., 2000; Kang et al., 2002; Jury and Vaux, 2005; Junya et al., 2017). This scenario leads to an increasing demand for irrigation water and may cause many serious problems, reducing mango crop yield, intensified pressure on water availability making it to an increasingly scarce resource and increasing the cost of irrigation water (Kirnak et al., 2005; Tognetti et al., 2005; Durán-Zuazo et al., 2011). Water stress decreases plant growth by reducing cell division and root enlargement; leads to lowering ion adsorption on the root surface. Also, deficit of water had adversely effect on different physiological process such as photosynthesis, translocation of sugars and phytohormones, ion uptake transport and assimilation, nitrogen fixation, cell turgidity and dark respiration, consequently, yield of different
crops was injured. (Fageria et al., 2006). Therefore, irrigation with precision and high water use efficiency (WUE) is essential, requiring deficit irrigation strategies in order to not compromise production (Spreer et al., 2009; Dos-Santos et al., 2016).

The development of different water-saving irrigation strategies such as regulated deficit irrigation (RDI) in order to save water and increase water use efficiency (WUE) in fruit crops under semiarid conditions were studied by Romero et al. (2004) and Khan et al. (2009). Regulated deficit irrigation (RDI) is the strategy of irrigation with deficits in developmental stages of the culture whose growth and fruit quality have low sensitivity to water stress, and normal irrigation in the other stages (Grant et al., 2004; Nakajima et al., 2004; Wakrim et al., 2005; Wahbi et al., 2005; Carlos et al., 2011). Regulated deficit irrigation management for the mango crop must follow technical criteria, so that water is applied at the right time and the right amount (Phene, 1991; Phene et al., 1992). Most studies have shown that deficit water applied during the slow fruit growth period could control excessive vegetative growth, while maintaining or even increasing crop yield. These included studies on mango cv. “Tommy Atkins” (Dos-Santos et al., 2016), cv. “Keitt” (Levin et al., 2017) and cv. “Banganpalli” (Subbaiah et al., 2017). Irrigation requirement and its effect on micro-nutrition in mango are still not well investigated, especially under the Mediterranean climate (Lechaudel et al., 2005).

Micronutrient deficiencies is one of the most important problems in the Mediterranean region, where the soils are characterized by high pH content, low carbon content, high salinity level, and low organic matter as well as have free calcium carbonate. Micronutrients are essential for different biological functions that might be attributed to tree yield and fruit quality (Shoeib and El-Sayed 2003; Prasad et al., 2012). In these soils, deficiencies of Zn can become severe (Tavallali and Rahemi, 2007) which lead to deficiency of synthesis of many enzymes needed for nitrogen metabolism, energy transfer, and protein synthesis (Beede et al., 2005), retards growth and yield of trees (Rosati et al., 2010; Hafeez et al., 2013), low fruit setting in many fruit crops (Mozafari, 2005; Gursoz et al., 2010) and limiting factors to fruit quality (Prasad et al., 2012). Also, Zn is required for the synthesis of tryptophan which is a precursor of IAA, it also has an active role in the production of an essential growth hormone auxin (Alloway, 2004; Brennan, 2005; Zagzog and Gad 2017).

Nanotechnology has provided the feasibility of exploiting nanostructured materials as fertilizers carries or controlled – release vectors for building of so-called smart fertilizer as new facilities to enhance nutrient use efficiency (Al-Amin and Jayasuriya, 2007). Utilization of foliar nanofertilizers is a new strategy has started to attract attention in agriculture currently increasingly growing in popularity day by day. The foliar sprays with nanofertilizers have been shown to be convenient for field use under high soil salinity, have a good effectiveness and very rapid trees response (Erdal et al., 2004; Fernández et al., 2013). They are also considered the most important promising approaches for sustainable agriculture with high production, low deterioration and feed the world grown rapidly (Sekhon 2014). The application of nanoparticles is an easy way to fertilizing plants, as they can increase transfer into the plant cell. On the basis of nanotechnology, some metals such as zinc oxide-based nanoparticles increase the permeability and create new holes in the cell wall. (Sondi and Salopek, 2004; Brayner et al., 2006). Substitution of nano-fertilizer with traditional fertilizers is approach to reduce nutrient losses, improve soil fertility and increase orchard profitability (Naderi and Abedi 2012; Mishra et al., 2016).

Therefore, this research aimed to study the effect of under regulated deficit irrigation (RDI) strategies and foliar spray of nano-zinc micronutrient (Zn NPs) on mango (Mangifera indica L.) cvs. "Nawomy" and "Sokary" yield and its components in El-Skiekh Zwaid region, North Sinai Governorate, Egypt.

**MATERIALS AND METHODS**

**Location of the study area and Climatic conditions**

The experiment was carried out on Mango trees (Mangifera indica L.) cvs. "Nawomy" and "Sokary" of about 16 years age at a commercial orchard in El-Skiekh Zwaid region, North Sinai Governorate, Egypt, in two successive seasons of 2016 and 2017. The study area is bounded by longitudes 33° 54’ 45.2” E and latitudes 30° 57’ 22” N. The maximum temperature of 30.1 and 30.6 °C in July meanwhile the lower one was 12.3 and 11.6°C in January in both seasons with the average annual mean temperature 21.3 °C. The all climatic data were collected from meteorological station of the Faculty of Environmental Agricultural Sciences at El-Arish, Arish University.

**Study treatments**

The study included three levels of irrigation water and three ZnSO4 NPs concentrations and their interaction. The three levels of irrigation water were 100 (as a control treatment), 75 and 50% of crop evapotranspiration (ETc). Trees were sprayed with different concentrations of nanoparticles of zinc micronutrient treatments (ZnSO4 NPs) at 0, 50, and 100 ppm. Trees were applied three times before flowering, 10 days after full bloom and after fruit set.
in both seasons. Spraying was done with a hand sprayer; the two mango varieties received uniform management practices including pruning, fertilizer, insecticide and pesticide applications.

The distances between the mango trees were 4×6 and 3×5 meter for Nawomy and Sokary mango cultivars, respectively and it’s were grown in sandy soil under drip irrigation system. Soil and water characteristics of the Mango orchard are presented in Tables (1 and 2) according to Van Reeuwijk (2002). The selected trees received the same horticultural practices.

### Table 1. Initial soil physical and chemical characteristics of the investigated orchard at El-Skiekh Zwaid region

| Parameter              | 0-30   | 30-60  | 0-30   | 30-60  |
|------------------------|--------|--------|--------|--------|
|                        | Season 2016 | Season 2017 |
| **Physical characteristics** |        |        |        |        |
| Sand gkg⁻¹             | 967    | 933.9  | 961    | 930.1  |
| Silt gkg⁻¹             | 14.1   | 25.1   | 13.3   | 24.9   |
| Clay gkg⁻¹             | 18.9   | 41.0   | 24.7   | 45.0   |
| Soil texture           | Sandy  | Sandy  | Sandy  | Sandy  |
| Bulk density Mg.m⁻³     | 1.57   | 1.59   | 1.58   | 1.61   |
| **Chemical characteristics** |        |        |        |        |
| pH                     | 8.34   | 8.40   | 8.21   | 8.35   |
| EC (dS.m⁻¹)            | 0.46   | 0.50   | 0.48   | 0.52   |
| Ca²⁺                   | 2.22   | 2.50   | 2.60   | 2.49   |
| Mg²⁺                   | 1.38   | 1.60   | 1.33   | 1.72   |
| Na⁺                    | 0.86   | 0.82   | 0.80   | 0.85   |
| K⁺                     | 0.14   | 0.08   | 0.07   | 0.14   |
| CO₃²⁻                  | -      | -      | -      | -      |
| HCO₃⁻                  | 2.60   | 1.30   | 2.50   | 1.40   |
| Cl⁻                    | 1.62   | 3.01   | 1.70   | 3.22   |
| SO₄²⁻                  | 0.38   | 0.69   | 0.60   | 0.58   |

### Table 2. Some water chemical analysis of the investigated artesian well at El-Skiekh Zwaid region

| pH | EC (dS.m⁻¹) | Cations (mmol.l⁻¹) | Anions (mmol.l⁻¹) |
|----|-------------|--------------------|-------------------|
|    | (ppm)       | Ca²⁺               | Mg²⁺              | Na⁺   | K⁺    | CO₃²⁻ | HCO₃⁻ | Cl⁻   | SO₄²⁻ |
|----|-------------|-------------------|------------------|-------|-------|-------|-------|-------|-------|
| 7.80 | 0.83       | 531.20            | 2.89             | 2.00  | 3.22  | 0.19  | -     | 4.25  | 2.40  | 1.65  |
| 7.85 | 0.84       | 537.60            | 2.98             | 2.20  | 3.03  | 0.21  | -     | 4.35  | 2.61  | 1.44  |

**Reference evapotranspiration (ETo)**

The ETc is the irrigation volume required to meet the crops evapotranspiration demand for the irrigation period. The Modified Blaney-Criddle method was used to determine reference evapotranspiration (ETo) recommended by Doorenbos and Pruitt (1977) and Allen et al. (1998), the equation was given as:

\[
ET_o = C \left[ p \left( 0.46 T + 8.13 \right) \right] \quad (\text{mm.day}^{-1})
\]

Where:

- \(ET_c\) = Reference crop evapotranspiration mm.day⁻¹ for the month considered.
- \(C\) = Adjustment factor which depends on minimum relative humidity (RH min), ratio of actual to maximum possible (tabulated) sunshine hours \((n/N)\) and daytime wind speed at 2 meters from the soil surface in m/sec \((U_2)\).
- \(p\) = Mean daily percentage of total annual day time hours for given month and latitude.
- \(T\) = Mean daily temperature in °C over the month considered.

**Crop evapotranspiration (ETc)**

Crop evapotranspiration (ETc) was calculated according to Doorenbos and Pruitt, (1977) and Allen et al. (1998) with the following formula:

\[
ET_{crop} = K_c \cdot ET_o \quad (\text{mm.day}^{-1})
\]

Where:
Kc = Crop coefficient.

ET₀ = Reference crop evapotranspiration (mm.day⁻¹).

Crop coefficients (Kc) with the adjustment of tree size were estimated from drainage lysimeters located in the same orchard. The Kc values estimated for mango trees during the irrigation period were about 0.66, 0.79, 0.91 and 0.88 at flowering, fruit set, fruit growth and fruit maturation, respectively according to Durán-Zuazo et al. (2011). "Nawomy" and "Sokary" mango were irrigated using a drip irrigation system, with two online drippers with emitters discharge of 4 L.h⁻¹ per tree, each was placed 50 cm from the tree-trunk base. Irrigation treatments were applied from March and continued until February of next year and were programmed weekly during the afternoon based on calculation crop evapotranspiration (Table 3).

Table 3. Amount of irrigation water (m³.ha⁻¹) for Nawomy and Sokary mango cultivars during 2016 and 2017 seasons.

| Parameter                      | Amount of irrigation water (m³.ha⁻¹) |
|--------------------------------|-------------------------------------|
|                                | 100%                  RDI-75%           RDI-50%           100%                  RDI-75%           RDI-50% |
| Month                          | "Nawomy" cv.          "Sokary" cv.       |
| March                          | 731.18                548.38            365.59            1169.89             877.41            584.93   |
| April                          | 794.30                595.74            397.15            1270.90             953.17            635.44   |
| May                            | 930.98                698.24            465.48            1489.57             1117.17           744.80   |
| June                           | 1068.38               801.30            534.19            1709.41             1282.06           854.71   |
| July                           | 1188.24               891.19            594.12            1901.19             1425.91           950.60   |
| August                         | 1017.16               762.89            508.58            1627.47             1220.61           813.75   |
| September                      | 920.94                690.70            460.48            1473.51             1105.13           736.75   |
| October                        | 866.56                649.91            433.28            1386.49             1039.87           693.25   |
| November                       | 761.89                571.41            380.94            1219.01             914.25            609.52   |
| December                       | 760.10                570.08            380.06            1216.16             912.11            608.09   |
| January                        | 118.98                89.23             59.50             190.38              142.78            95.18    |
| February                       | 118.71                89.04             59.36             189.95              142.47            94.99    |
| Total                          | 9277.43               6958.10           4638.74           14843.92            11132.93         7421.98   |

Note: RDI refers to regulated deficit irrigation

Data recorded and measurements:

Water relationships

Consumptive use of water (CU): It was calculated using the equation given by Israelson and Hansen (1962) as follows:

\[ CU = D \times AD \times [(e_z - e_i) \times 100] \]

Where:

\( \begin{align*} 
C_U & = \text{Consumptive use of water in cm}, \\
D & = \text{Irrigated soil depth in cm}, \\
AD & = \text{Bulk density, gm cm}^3, \text{ of the chosen irrigated soil depth}, \\
e_z & = \text{Soil moisture percent after irrigation}, \text{ and} \\
e_i & = \text{Soil moisture percent before the next irrigation}. 
\end{align*} \]

Water use efficiency (WUE): The consumed water by mango trees was calculated according to Yaron et al., (1973) as follows:

\[ WUE = \frac{Y}{ETa} \]

Where:

\( \begin{align*} 
WUE & = \text{Water use efficiency,} \\
Y & = \text{Crop yield (kg.ha}^{-1}, \text{ and} \\
ETa & = \text{Evapotranspiration (m}^3.\text{ha}^{-1}). 
\end{align*} \]

The actual evapotranspiration, ETa, is assumed to be synonymous to the calculated consumptive use of water (CU). Consequently, daily and monthly consumptive use of water were calculated for specified soil depths for all treatments.

The yield reduction and water saving: They were calculated from the following equations according to Ismail, (2010) as follows:

\[ YR = 100 - \left( \frac{Y \text{ of RDI - 75 or 50% of WR}}{Y \text{ of 100% of WR}} \right) \times 100 \]
IWS

= \frac{100 \left[ CU \frac{\text{of} \text{RDI} - 75 \text{or} 50\% \text{of} \text{WR}}{CU \text{of} 100\% \text{of} \text{WR}} \right] \times 100}{\text{Where:}}

Y = \text{Yield}  \\
WR = \text{Water requirements}  \\
CU = \text{Water consumption}  \\
YR = \text{Yield reduction}  \\
IWS = \text{Irrigation water saver}

**Plant measurements**

At maturity stage of "Nawomy" and "Sokary" mango fruits, the yield (kg.tree⁻¹) was estimated by multiplying fruits number per tree. In addition, mean fruit weight (g), fruit length (cm), fruit width (cm), fruit size (cm²), fruit TSS (%), fruit acidity (%) and fruit total sugars (TSS %) according to the methods in association of official analytical chemists (A.O.A.C., 1999) were determining.

**Experiment design and statistical analysis**

The treatments were arranged in different experimental plots using a randomized complete blocks design (as a factorial experiment). Each treatment was replicated thrice and each replicate was consisted of two trees. All measured variables occurred under the influence of two factors as follows: the 1st factor was concentrations of NPs-Zn which have three levels (0, 50, and 100 ppm of ZnSO4 NPs, whilst, the 2nd factor one was irrigation treatments which have three levels (100, 75 and 50% of ETc). Data were statistically analyzed using MSTATC computer program (Russell, 1986). The two-way ANOVA test was performed to determine the effect of studied factors (i.e. NPs-Zn concentration and irrigation treatments) on the measured variables. If the p-value is less than 0.05, we reject the null hypothesis that there's no difference between the means and conclude that a significant difference does exist. If the p-value is larger than 0.05, we cannot conclude that a significant difference exists (Steel and Torrie, 1980). The ANOVA test was followed by post hoc test using Duncan multiple range (DMR) test for comparisons between means of differences treatments (Duncan, 1955). The means followed by the same letter in each column are not significantly different from each other at the 5-percent probability level.

**RESULTS AND DISCUSSION**

1. Water relationships

1.1. Actual evapotranspiration (ETa)

Water consumptions were computed from the data of soil moisture depletions; i.e., the differences between soil moisture contents before and after irrigations. Results in Table (4) show that, the ETa (m³.ha⁻¹), for mango "Nawomy" and "Sokary" during the two investigated seasons were affected by regulated deficit irrigation. They obviously decreased with increasing deficit irrigation. Their highest total monthly values were 8689.81 and 8187.59 m³.ha⁻¹, for "Nawomy", and 13903.69 and 13100.14 m³.ha⁻¹ for "Sokary" obtained with 100% irrigation treatment, in the first and second growth seasons, respectively. The lowest ones were 4103.52 and 3826.80 m³.ha⁻¹ for "Nawomy", and 6797.36 and 6051.70 m³.ha⁻¹ for "Sokary" with 50% irrigation treatment in the first and second growth seasons, respectively. Consequently, the average total consumed water for both seasons were 8442.07, 6301.00 and 3966.76 m³.ha⁻¹, for Nawomy and 13507.31, 9912.29 and 6427.10 m³.ha⁻¹ for Sokary plants irrigated with 100, 75% and 50% of ETc, respectively.

It could notice that, the value of the wet surface area per hectare that used for the calculation of total volumes of water was 10000 m², due to the fact that all experimental plots surface areas were moistened during irrigation. Also, the total applied volumes of irrigation water for "Naomy" or "Sokary" plants, in both seasons were 9281.17, 6960.88 and 4640.57 m³, ha⁻¹; and 14849.86, 11137.40 and 7424.93 m³, ha⁻¹ for 100, 75 and 50% of ETc in first and second seasons, respectively. Hence, as the total applied irrigation water increases the total consumed water also increases. Apparently, there is a critical limit for the ratio of the depth of consumed water to the depth of applied water. In respect to the variations in daily ETa values, it generally increased from February till July.
Table (4): Actual evapotranspiration (m$^3$.ha.$^{-1}$) for "Nawomy" and "Sokary" mango cultivars during 2016 and 2017 seasons.

| Parameter | Actual evapotranspiration (m$^3$.ha.$^{-1}$) | "Nawomy" cv. | "Sokary" cv. |
|-----------|---------------------------------------------|---------------|---------------|
|           | 100% | RDI-75% | RDI-50% | 100% | RDI-75% | RDI-50% |
| Month     |      |        |        |      |        |        |
| March     | 706.63 | 535.86 | 333.69 | 1130.61 | 838.54 | 552.75 |
| April     | 772.45 | 585.78 | 364.77 | 1235.92 | 916.65 | 604.23 |
| May       | 877.80 | 665.67 | 414.52 | 1404.48 | 1041.66 | 686.63 |
| June      | 1041.56 | 789.85 | 491.85 | 1666.49 | 1235.98 | 814.73 |
| July      | 1142.16 | 866.14 | 539.36 | 1827.46 | 1355.37 | 893.43 |
| August    | 908.94 | 689.28 | 429.22 | 1454.31 | 1078.61 | 711.00 |
| September | 850.16 | 644.70 | 376.87 | 1360.26 | 947.06 | 624.28 |
| October   | 798.09 | 605.21 | 314.04 | 1235.92 | 838.54 | 552.75 |
| November  | 702.51 | 532.73 | 331.74 | 1124.01 | 833.64 | 549.52 |
| December  | 698.62 | 529.78 | 329.90 | 1117.78 | 829.02 | 546.47 |
| January   | 96.22 | 72.96 | 45.44 | 153.95 | 114.18 | 75.26 |
| February  | 94.67 | 71.79 | 44.71 | 151.48 | 112.34 | 74.05 |
| Total     | 8689.81 | 6589.77 | 4103.52 | 13903.69 | 10311.90 | 6797.36 |

| Month     | 100% | RDI-75% | RDI-50% | 100% | RDI-75% | RDI-50% |
|-----------|------|---------|---------|------|---------|---------|
| March     | 623.03 | 457.11 | 291.20 | 996.85 | 723.26 | 460.50 |
| April     | 671.91 | 492.97 | 314.04 | 1075.05 | 780.00 | 496.63 |
| May       | 815.70 | 598.48 | 381.25 | 1305.12 | 946.92 | 602.91 |
| June      | 901.13 | 661.15 | 421.18 | 1441.80 | 1046.09 | 666.05 |
| July      | 1018.83 | 747.51 | 476.19 | 1630.12 | 1182.72 | 753.05 |
| August    | 942.45 | 691.47 | 440.49 | 1507.92 | 1094.06 | 696.59 |
| September | 825.48 | 605.66 | 385.82 | 1320.78 | 958.28 | 610.14 |
| October   | 778.64 | 571.29 | 363.93 | 1245.83 | 903.90 | 575.52 |
| November  | 683.75 | 501.66 | 319.58 | 1093.99 | 793.74 | 505.38 |
| December  | 684.44 | 502.17 | 319.90 | 1095.11 | 794.55 | 505.89 |
| January   | 120.57 | 88.46 | 56.35 | 192.91 | 139.96 | 89.11 |
| February  | 121.67 | 89.27 | 56.87 | 194.67 | 141.24 | 89.93 |
| Total     | 8187.59 | 6007.20 | 3826.80 | 13100.14 | 9504.72 | 6051.70 |

Note: RDI refers to regulated deficit irrigation.

1.2. Water use efficiency (WUE)

The water use efficiency for full and deficit irrigation treatments are presented in Tables (5 and 6). Increasing the irrigation deficit gained a high increase in the WUE. The highest value of WUE was obtained with 50% of IWR treatment, while the lowest one was recorded with 100% of IWR treatment. The difference in WUE between 100% of IWR and 75% of IWR was slight compared to that between 75% of IWR and 50% of IWR treatments; however, these differences were significant in the two tested seasons.

A sharp increase in WUE was obtained by deficit irrigation. This indicates that water movement into fruits may be decreased with the progressive in water deficit without any effect on the translocation of dry matter into the seed and this effect resulted in an increase in mass production per unit of water, which in turn increased water use efficiency.

The water use efficiency for addition of ZnSO$_4$ NPs fertilization treatments are presented in Tables (5 and 6). Increasing the addition of nano Zn fertilization gained a high increase in the WUE. The highest value of WUE was obtained with addition of 100 ppm of nano Zn fertilization treatment, while the
lowest one was recorded with no addition of nano Zn fertilization treatment. The difference in WUE between addition of 100 ppm of nano Zn fertilization and addition of 50 ppm of nano Zn fertilization was slight compared to that between addition of 100 ppm of nano Zn fertilization and no addition of nano Zn fertilization treatments.

Data in Tables (5 and 6) show the effect of interaction between regulated deficit irrigation and ZnSO₄ NPs fertilization on water use efficiency for "Nawomy" and "Sokary" mango cultivars during 2016 and 2017 seasons. The highest values were recorded with the interaction between 50% irrigation treatment with 100 ppm nano Zn fertilization treatment (1.259, 1.01 and 1.491, 1.28 with Nawomy and Sokary mango plant in the first and second season, respectively). However, the lowest values were recorded with the interaction between 100% irrigation treatment and no nano Zn fertilization treatment (0.827, 0.650 and 0.931, 0.72 in the first and second season, respectively). Similarly, the results of this study are in agreement with Spreer et al. (2009) who concluded that a potential to increase water-use efficiency (WUE) of "Chok Anan" mango was obtained by deficit irrigation. Also, Junya et al. (2017) concluded that comprehensive evaluation of the effect of indexes of correlation on irrigation treatment by subordinate function showed that when the soil moisture content were controlled at about 65–70% of the field water moisture capacity, water demand in the growth and development of mango could be ensured, and maximum production efficiency of irrigation and the best quality of fruit could be achieved.

1.3. Yield reduction (YR) and irrigation water saving (IWS)

Obviously, deficit irrigation saves water but reduces the yield (Tables 5 and 6). Irrigating Nawomy trees with 75% of irrigation water requirements increased the total yield by (6.35% and 5.01%) and saved about (24.16% and 26.63%) of (IWR) in the 1st and 2nd seasons, respectively. Increasing the deficit irrigation to 50% of IWR resulted in a severe yield reduction (29.20 % and 24.30%), but increased the water saving to about 51.11% and 53.80% of IWR in the 1st and 2nd seasons, respectively. From the present study, it could observe that the highest fruit yield was obtained from plants grown with no-stress (100% of IWR), while, deficit irrigation decreased fruit yield. The amount of saved water increased sharply by deficit irrigation treatments. In conclusion, deficit irrigation could be considered as a suitable irrigation technique for mango production, where the benefit from saving large amounts of water outweighs the decrease in total yield.

Data in Tables (5 and 6) show the effect of ZnSO₄ NPs fertilization on reduction of yield. Addition of 100 ppm of nano Zn fertilization to Nawomy plants increased the total yield by 5.83% and 5.44% in the first and second seasons, respectively, while the low concentration (50 ppm) resulted in a severe yield increasing (0.62% and 2.88%) in the first and second seasons, respectively. On the other hand, addition of 100 ppm of nano Zn fertilization to Sokary plants increased the total yield by 7.67% and 11.02% in the 1st and 2nd seasons, respectively, while, the low concentration (50 ppm) resulted in yield reduction of 2.78% and increased 0.82% in the first and second seasons, respectively. It could conclude that the highest fruit yield was obtained from plants grown with addition of 100 ppm of nano Zn fertilization.

Data in Tables (5 and 6) show the effect of interaction between regulated deficit irrigation and ZnSO₄ NPs fertilization on irrigation water saving (%), reduction in yield (%) for “Nawomy” and “Sokary” mango cultivars during 2016 and 2017 seasons. The results show that the best treatments were the interaction between 75% irrigation treatment with addition of 100 ppm nano Zn treatment, where this interaction saved water of about 24.17, 25.83 and 26.63, 27.45% with Nawomy and Sokary plants which was reflected on increased yield of about 13.62, 23.10 and 14.10, 22.91% in the first and second season, respectively. The data show that the highest increase in yield was with the interaction between 100% irrigation treatment with 100 ppm nano Zn treatment, while the highest reduction was recorded with the interaction between 50% irrigation treatment with no addition of nano Zn fertilization.
Table 5. Effect of interaction between regulated deficit irrigation and ZnSO₄ NPs fertilization on irrigation water saving (%), reduction in yield (%) and water use efficiency (kg.m⁻³) of "Nawomy" mango cultivar during 2016 and 2017 seasons

| Parameter | WUE (kg.m⁻³) | IWS (%) | YR (%) |
|-----------|--------------|---------|--------|
|           | 100% of ETc  | RDI-75% of ETc | RDI-50% of ETc | Mean of Zn | RDI-75% of ETc | RDI-50% of ETc | Mean of Zn | RDI-75% of ETc | RDI-50% of ETc | Mean of Zn |
| Zn T. (ppm) |              |         |       |       |              |         |       |              |         |       |       |
| 0         | 0.827        | 1.076   | 1.061 | 0.988 | 0.00         | 1.39   | 39.46 | 13.617       |
| 50        | 0.884        | 1.165   | 1.205 | 1.085 | -6.89        | -6.84  | 31.23 | -5.83        |
| 100       | 0.963        | 1.239   | 1.259 | 1.154 | 24.167       | 52.778 | 25.65 | -16.40       |
| Mean of RDI | 0.891        | 1.160   | 1.175 |        | -7.76        | -6.357 | 32.95 |

First season (2016)

| Second season (2017) |
|----------------------|---------------|
| 0                    | 0.931         | 1.238   | 1.169 | 1.113 | 0.00 | 2.40 | 37.78 | 13.393 |
| 50                   | 0.995         | 1.311   | 1.38  | 1.229 | -6.89 | -3.33 | 26.54 | -5.44 |
| 100                  | 1.072         | 1.448   | 1.491 | 1.337 | 26.63 | 53.261 | 26.63 | -7.36 |
| Mean of RDI          | 0.999         | 1.332   | 1.347 |         | -7.36 | -5.010 | 28.317 |

Notes: RDI, WUE, IWS, YR refers to regulated deficit irrigation, Water use efficiency, Irrigation water Save and Reduction in yield and the negative sign in the tables indicates an increase in the crop, respectively.

Table 6. Effect of interaction between regulated deficit irrigation and ZnSO₄ NPs fertilization on irrigation water saving (%), reduction in yield (%) and water use efficiency (kg.m⁻³) of "Sokary" mango cultivar during 2016 and 2017 seasons

| Parameter | WUE (kg.m⁻³) | IWS (%) | YR (%) |
|-----------|--------------|---------|--------|
|           | 100% of ETc  | RDI-75% of ETc | RDI-50% of ETc | Mean of Zn | RDI-75% of ETc | RDI-50% of ETc | Mean of Zn | RDI-75% of ETc | RDI-50% of ETc | Mean of Zn |
| Zn T. (ppm) |              |         |       |       |              |         |       |              |         |       |       |
| 0         | 0.65         | 0.87    | 0.85  | 0.790 | 0.00         | 0.52   | 35.94 | 12.153       |
| 50        | 0.72         | 0.96    | 0.96  | 0.880 | -10.11       | -9.59  | 28.04 | 2.78         |
| 100       | 0.80         | 1.08    | 1.01  | 0.963 | 25.833       | 51.111 | 25.65 | -23.54       |
| Mean of RDI | 0.723        | 0.970   | 0.940 |         | -11.21       | -10.723 | 29.200 |

First season (2016)

| Second season (2017) |
|----------------------|---------------|
| 0                    | 0.72          | 1.03    | 1.03  | 0.927 | 0.00 | -3.75 | 30.92 | 9.057 |
| 50                   | 0.84          | 1.13    | 1.08  | 1.017 | -16.34 | -13.65 | 27.53 | -0.82 |
| 100                  | 0.90          | 1.22    | 1.28  | 1.133 | 27.446 | 53.804 | 27.08 | -24.61 |
| Mean of RDI          | 0.820         | 1.127   | 1.130 |         | -13.65 | -13.437 | 24.303 |

Notes: RDI, WUE, IWS, YR refers to regulated deficit irrigation, Water use efficiency, Irrigation water Save and Reduction in yield and the negative sign in the tables indicates an increase in the crop, respectively.
2. Fruit set percentage

As shown in Table (7), fruit set percentage was significantly improved in response to spraying nanoparticles of Zn micronutrient at 100 ppm on both mango cultivars during both seasons as compared to the control treatment (without Zn spray). The increasing in number of set fruits was associated with increasing concentrations of nano Zn micronutrient. The highest values of fruit set were detected on the Nawomy and Sokary mango trees that sprayed with NPs-ZnSO₄ at 100 ppm (13.09 and 13.50 %) and (12.17 and 12.55 %) during both seasons. The untreated trees produced the lowest values (10.82 and 10.96 %) and (10.41 and 10.65%) during both seasons.

Data in Table (7) show the effect of RDI treatments on fruit set % of Nawomy and Sokary mango trees, it could be noticed that trees irrigated with 100 and 75 % of ETC gave the highest values of fruit set percentage in both seasons, respectively compared to 50% of ETC treatment which recorded the lowest values in this respect. Concerning the interaction between the two factors under study, the highest values were recorded with application of 100% of 75% of ETC +100 ppm nano Zn treatments without significant differences between them in both seasons, while, the 50% of ETC + no nano Zn had the most depressive effect in this respect. These results are matched with those of Kamiab and Zamanibrahramabadi (2016) who found that the highest percentages of initial and final fruit set and yield per shoot were observed in "Shokufeh Almond" cultivar with nano-chelate super plus ZFM 2g/l (Zinc, Iron and Manganese), fertilizer spraying in two stages and the lowest percentage of initial and final fruit set was observed in control treatment in all tested cultivars.

3. Total yield and number of fruits per tree

Data in Table (7) show the effect of nanoparticles of Zn micronutrient, regulated deficit irrigation and their interaction treatments on yield (Kg.tree⁻¹) of "Nawomy" and "Sokary" mango cvs. during 2016 and 2017 seasons. Concerning, the nanoparticles effect, NPs-ZnSO₄ at 100 ppm treatment gave the highest significant values (17.37 and 18.56 kg.tree⁻¹) on Nawomy and Sokary mango cvs. (14.59 and 15.53 kg.tree⁻¹) in both seasons, respectively. Regarding to RDI treatments effect, 100 % and 75 % of ETC treatments showed a higher significant values (18.60 and 19.65 kg. tree⁻¹); (18.36 and 19.22 kg. tree⁻¹) on Nawomy cv. and (15.07 and 16.07 kg. tree⁻¹); (15.00 and 16.04 kg. tree⁻¹) on Sokary mango cvs. compared to 50% of ETC treatment in both seasons, respectively. Subbaiah et al. (2017) found that the maximum fruit number, yield per tree, fruit weight and total sugars were observed in RDI at 100 % Ep, followed by PRD at 75% Ep on Banganpalli mango trees during two seasons. The interaction between the two studied factors, 100 and RDI-75 % of ETc with NPs-ZnSO₄ at 100 ppm treatments gave the highest values (20.09 and 21.08 kg.tree⁻¹); (19.61 and 20.88 kg.tree⁻¹) for "Nawomy" cv. and (16.74 and 17.62 kg.tree⁻¹); (16.68 and 17.38 kg.tree⁻¹) for "Sokary" cv. in both seasons, respectively. However, 50 % of ETc without NPs-ZnSO₄ treatment gave the lowest values (10.45 and 10.74 kg.tree⁻¹) for "Nawomy" cv. and (8.68 and 9.36 kg.tree⁻¹) for "Sokary" in both seasons, respectively. These results are in harmony with those obtained by Zagzog and Gad (2017) on mango trees and El-Said et al. (2019) who worked on Flame Seedless Grape using five levels of of nano-zinc (0, Zinc sulphat at 565 ppm, Zinc EDTA at 140 ppm, nano zinc at 0.4 ppm, nano zinc at 0.8 ppm and nano zinc at 1.2 ppm). They showed that 0.4, 0.8 and 1.2 ppm of nano-zinc had a significant increase in yield compared with the conventional fertilizer.

As for the nanoparticles effect on number of fruits per tree, data in Table (8) revealed that number of fruits per tree was significantly improved owing to spraying Nawomy and Sokary mango trees with NPs-ZnSO₄ fertilization compared to the control. Spraying NPs-ZnSO₄ at 100 ppm was significantly superior than using NPs-ZnSO₄ at 0.00 or 50 ppm in improving the number of fruits per tree in both seasons. Concerning, the effect of RDI treatments, data in the same table clearly show that increasing amount of irrigation water from 50 to 100% ETC had no significant promotion on number of fruits per tree for "Nawomy" and "Sokary" mango cvs. in the first season, while trees irrigated with 100 and RDI-75 % of ETC gave the highest values of number of fruits per tree (47.42 and 46.42) and (34.67 and 35.66) for "Nawomy" and "Sokary" mango cvs. in the second season, respectively. Regarding the interaction between nanoparticles and regulated deficit irrigation treatments, the irrigation treatments with NPs-ZnSO₄ were significantly interactive for number of fruits per tree. The highest number of fruits per tree was given by 100% of ETC + NPs-ZnSO₄ at 100 ppm for "Nawomy" cv. and 100 or 75% of ETC + NPs-ZnSO₄ at 100 ppm for "Sokary" cv. in both seasons. However, RDI-50% of ETC without NPs-ZnSO₄ treatment had the lowest number of fruits per tree for the two cultivars in the both seasons. These observations are supported by the previous findings of Davarpanah et al. (2016) who reported that the foliar sprays of nano-fertilizers of zinc (636 mg Zn tree⁻¹) increased pomegranate fruit yield, and this was mainly due to increases in the number of fruits per tree.
Table 7. Effect of regulated deficit irrigation (RDI) and ZnSO₄ NPs fertilization treatments on fruit set and total yield per tree of "Nawomy" and "Sokary" mango cultivars during 2016 and 2017 seasons

| Zn T. (ppm) | "Nawomy" cv. | "Sokary" cv. | Total yield (kg.tree⁻¹) |
|-------------|--------------|--------------|-----------------------|
|             | 100% of ETC | RDI-75% of ETC | Mean | RDI-50% of ETC | Mean | RDI-75% of ETC | Mean | RDI-50% of ETC | Mean |
| 0           | 11.75 c      | 10.09 e      | 10.82C | 10.04c | 10.72cd | 9.56e | 10.41C | 17.26 c | 17.02 c | 10.45 f | 14.91 C | 13.55 c | 13.48 c | 8.68 f | 11.90 C |
| 50          | 12.28 b      | 11.75 c      | 11.33 cd | 11.79B | 11.83ab | 11.66b | 10.08d | 11.19B | 18.45 b | 18.44 b | 11.87 e | 16.25 B | 14.92 b | 14.85 b | 9.75 e | 13.17 B |
| 100         | 13.70 a      | 13.65 a      | 11.91 bc | 13.09A | 12.92a | 12.81a | 10.77cd | 12.17A | 20.09a | 19.61a | 12.40 d | 17.37 A | 16.74 a | 16.68 a | 10.35 d | 14.59 A |
| Mean        | 12.58 A      | 12.01 A      | 11.11 B | 11.90A | 11.73A | 10.14B | 18.60 A | 18.36 A | 11.57 B | 15.07 A | 15.00 A | 9.59 B |

First season (2016)

Second season (2017)

Means having the same alphabetical litter (s) are not significantly different at 0.05 level according to Duncan's multiple range test.

Table 8. Effect of regulated deficit irrigation (RDI) and ZnSO₄ NPs fertilization treatments on number of fruits per tree of "Nawomy" and "Sokary" mango cultivars during 2016 and 2017 seasons

| Zn T. (ppm) | "Nawomy" cv. | "Sokary" cv. |
|-------------|--------------|--------------|
|             | 100% of ETC | RDI-75% of ETC | Mean | RDI-50% of ETC | Mean |
| 0           | 63.50d       | 62.83c       | 60.31g | 62.21C | 51.74c | 51.83c | 49.41e | 50.99C |
| 50          | 65.46b       | 64.24c       | 61.43f | 63.71B | 54.99b | 54.46b | 50.65d | 53.37B |
| 100         | 66.26a       | 65.89ab      | 63.27de | 65.14A | 56.39a | 56.24a | 54.97b | 55.87A |
| Mean        | 65.07A       | 64.32B       | 61.67C | 54.37A | 54.18A | 51.68B |

Number of fruits.tree⁻¹

First season (2016)

Second season (2017)

Means having the same alphabetical litter (s) are not significantly different at 0.05 level according to Duncan's multiple range test.
4. Fruit physical characteristics

4.1. Fruit weight and size

Data presented in Table (9) reveal that fruit weight and volume were affected significantly by different concentration of NPs-ZnSO₄ fertilization treatments in both seasons. The highest fruit weight and volume values were recorded by NPs-ZnSO₄ at 100 ppm, followed by NPs-ZnSO₄ at 50 ppm in the both seasons. On the contrary, the lowest values were detected in NPs-ZnSO₄ at 0 ppm (control) treatment. The enhancement in fruit weight and size may be due to the catalytic action of micronutrients particularly at higher concentration (NPs-ZnSO₄ at 100 ppm). Hence, the foliar application of nano zinc quickly increased the uptake of macronutrients in the tissues and organs of the mango plants, decreased the nutritional deficiencies and improved fruit quality. These results are in harmony with those obtained by Al-Amin and Jayasuriya (2007). As for the effect of regulated deficit irrigation (RDI) treatments on fruit weight and volume, data in the same table show that the irrigating mango trees with 100% of ETc and RDI-75 % of ETc showed the most effective effect on fruit weight and volume as compared with irrigating trees with RDI-50 % of ETc in both seasons. Regarding the interaction effect, data in the same table indicate that the highest fruit weight and volume were observed in RDI-100 % or RDI-75 % of ETc + NPs-ZnSO₄ at 100 ppm, while, the lowest ones were obtained with irrigating trees with RDI-50 % of ETc without applying NPs-ZnSO₄ in both seasons.

4.2. Fruit length and width

The obtained results from (Table 10) show that fruit length and width of "Nawomy" mango cultivar was affected by foliar application of NPs-ZnSO₄ fertilization and the highest values of fruit length and width were recorded with NPs-ZnSO₄ at 100 ppm, followed by NPs-ZnSO₄ at 50 ppm in comparison to NPs-ZnSO₄ at control (without Zn applications) in both seasons. However, there were no significant differences among NPs-ZnSO₄ treatments on "Sokary" cv. in both seasons. As for regulated deficit irrigation (RDI) effect, the highest values of fruit length and width were found with applying RI-100 % followed by RDI-75% of ETc without significant differences compared to RDI-50 % of ETc treatment. Concerning, the interaction effect between regulated deficit irrigation (RDI) and application of NPs-ZnSO₄ treatments, data in the same table show that irrigating trees with RDI-100 % and RDI-75 % of ETc + spraying NPs-ZnSO₄ at 100 ppm gave the highest fruit length and width, while RDI-50 % of ETc without NPs-ZnSO₄ treatment had the lowest fruit length and fruit width in both seasons. These results are in harmony with those obtained by Zagzog and Gad (2017), who found that nano-zinc treatments recorded the highest values of fruit length and width as well as increased yield as number of fruit or weight per tree of mango trees. Also, Razzaq et al. (2013) reported that trees sprayed with 0.6% zinc sulfate exhibited highest increase in fruit diameter and fruit weight compared to control treatment with better fruit quality in ‘Kinnow’ mandarin.

5. Fruit chemical characteristics of the fruit

5.1. Total soluble solids (TSS %) and total reducing sugars

Data in Table (11) show that foliar application of NPs-ZnSO₄ positively improved total soluble solids percentage (TSS %) and total sugar in juice of "Nawomy" and "Sokary" mango cultivars. The statistical analysis show that the highest values of total soluble solids in juice (TSS %) and total sugar were recorded with spraying 100 ppm NPs-ZnSO₄ treatment, followed by 50 ppm NPs-ZnSO₄ in both seasons. Data also reveal that in both study seasons, total soluble solids percentage in fruit juice (TSS %) and total sugar percentages were increased linearly with increasing the amount of irrigation water. The irrigating trees with RDI 100 % ETc gave the highest TSS % and total sugar values, followed by RDI-75 % of ETc in 2016 and 2017 seasons. On the other hand, irrigating trees with RDI- 50% of ETc had the most depressive effect on total soluble solids (TSS %) and total sugar values in both
seasons. These results are matched with those of Gugulethu (2006) who reported that the RDI treatment (75 % of the amount of irrigation water applied) improved the total soluble solids concentration (TSS %) of "Kent" mango fruits.

Data presented in Table (11) indicate that total soluble solids (TSS%) and total reducing sugar were significantly influenced by the interaction between different irrigation levels and NPs-ZnSO₄ treatments. The highest TSS % and total reducing sugar were noticed with applying irrigation water at 100 % of ETc with spraying NPs-ZnSO₄ at 100 ppm treatment which did not differ statistically than RDI-75 % of ETc with spraying NPs-ZnSO₄ at 100 ppm treatment in 2016 and 2017seasons. However, the lowest TSS % and total reducing sugar values were recorded with applying RDI-50% of ETc without spraying NPs-ZnSO₄ in both seasons. These results are matched with those of Davarpanah et al. (2016) who found that foliar sprays of nano-fertilizers of zinc increased total soluble solids (TSS %) and decreased total acidity (TA) of pomegranate fruits cv. "Ardestani". Also, Razzaq et al. (2013) found that foliar application of zinc sulfate up to 0.6% improved ascorbic acid content with better fruit quality in ‘Kinnow’ mandarin.

5.2. Total acidity and ascorbic acid content

Concerning total acidity percentage, data in Table (12) show that there were no significant differences among regulated deficit irrigation treatments and spraying mango with nano-zinc in both seasons. Total acidity percentage showed close values (1.31 and 1.44 %); (1.32 and 1.48 %) for "Nawomy" and (1.16 and 1.31%); (1.21 and 1.33%) for "Sokary" mango cultivars in first and second seasons, respectively. As, regard to the specific effect of foliar application of NPs-ZnSO₄ on ascorbic acid content (mg/ 100 g of pulp), data in Table (13) show that nano-zinc application caused the highest significant increase in ascorbic acid values. The highest values were obtained with NPs-ZnSO₄ at 100 ppm treatment (34.78 and 35.81 mg/ 100 g of pulp) for Nawomy and (25.50 and 26.31 mg/ 100 g of pulp) for Sokary mango trees, followed by NPs-ZnSO₄ at 50 ppm treatment (34.24 and 34.64 mg/ 100 g of pulp) for Nawomy and (25.12 and 25.58 mg/100 g of pulp) for Sokary mango trees during first and second seasons, respectively. However, the lowest values of ascorbic acid were noticed with non-sprayed trees in both seasons. Table (12) reveal that irrigating trees with 100 % and RDI-75 % of ETc gave the highest ascorbic acid values as compared to RDI- 50 % of ETc which had the most depressive effect of ascorbic acid values in both seasons. Regarding, the interaction effect between regulated deficit irrigation (RDI) and nano-zinc applications, the results in the same table indicate that ascorbic acid content of both mango cultivars was increased due to regulated deficit irrigation + nano- zinc treatments. Furthermore, the irrigating trees with RDI-100 or RDI-75 % of ETc + NPs-ZnSO₄ at 100 ppm treatments proved to be the superior interaction treatment in increasing ascorbic acid values in both seasons. However, irrigating trees with 50% of ETc + without NPs-ZnSO₄ treatment gave the lowest ascorbic acid values. These observations are supported by the previous findings by various workers (Anees et al., 2011; Kumar and Singh, 2018) on mango trees who revealed that the application of foliar spray of ZnSO₄ at 0.4 % + Boric acid at 0.2 % + CuSO₄ at 0.2 % significantly increased the chemical properties of fruits than the control. Whereas, trees sprayed with ZnSO₄ showed the maximum total soluble solids, ascorbic acid and non-reducing sugars with low acidity in comparison to rest of control.
Table 9. Effect of regulated deficit irrigation (RDI) and ZnSO₄ NPs fertilization treatments on fruit weight and size of "Nawomy" and "Sokary" mango cultivars during 2016 and 2017 seasons

| Zn T. (ppm) | "Nawomy" cv. | "Sokary" cv. | Fruit weight (g) | Mean | "Nawomy" cv. | "Sokary" cv. | Fruit size (ml) | Mean |
|-------------|--------------|--------------|------------------|------|--------------|--------------|----------------|------|
| 100% of Etc | RDI-75% of Etc | RDI-50% of Etc | 100% of Etc | RDI-75% of Etc | RDI-50% of Etc | 100% of Etc | RDI-75% of Etc | RDI-50% of Etc | Mean |
| 0           | 271.81b      | 270.89b      | 173.27d          | 238.66B | 261.89c      | 260.08c      | 175.67f         | 232.55C | 333.69b      | 328.18b      | 248.71d         | 303.53C | 326.60ab | 315.21b | 243.88d | 295.23B |
| 50          | 281.85ab     | 287.05ab     | 193.23c          | 254.04AB | 271.32b      | 272.68b      | 192.50d         | 245.50B | 349.52ab     | 339.31b      | 262.58cd        | 317.14B | 348.07a | 319.71b | 245.87d | 304.55A |
| 100         | 303.20a      | 297.62a      | 195.99c          | 265.60A  | 296.86a      | 296.59a      | 188.28c         | 260.58A  | 361.33a      | 358.34a      | 300.92c         | 340.20A  | 351.90a | 322.02ab | 252.90c | 308.94A |
| Mean        | 285.62A      | 285.19A      | 187.49B          |       | 276.69A      | 276.45A      | 185.48B         |       | 348.18A      | 341.94A      | 270.74B         | 342.19A  | 318.98B | 247.55C |

Means having the same alphabetical litter (s) are not significantly different at 0.05 level according to Duncan's multiple range test.

Second season (2017)

| Zn T. (ppm) | "Nawomy" cv. | "Sokary" cv. | Fruit weight (g) | Mean | "Nawomy" cv. | "Sokary" cv. | Fruit size (ml) | Mean |
|-------------|--------------|--------------|------------------|------|--------------|--------------|----------------|------|
| 100% of Etc | RDI-75% of Etc | RDI-50% of Etc | 100% of Etc | RDI-75% of Etc | RDI-50% of Etc | 100% of Etc | RDI-75% of Etc | RDI-50% of Etc | Mean |
| 0           | 276.74b      | 273.03b      | 179.46d          | 243.08B | 269.17b      | 279.50b      | 191.41d         | 246.70B | 353.71b      | 344.59c      | 228.81e         | 309.04C | 346.20a | 330.97a | 224.37b | 300.51B |
| 50          | 291.37ab     | 291.09ab     | 214.81c          | 265.76AB | 305.16a      | 297.10a      | 193.79d         | 265.35AB | 370.49ab     | 356.28b      | 241.57de        | 322.78B | 368.95a | 335.70a | 231.12b | 311.92AB |
| 100         | 305.42a      | 303.25a      | 215.95c          | 274.87A  | 300.91a      | 297.55a      | 214.98c         | 271.15A  | 383.01a      | 381.63a      | 288.88d         | 351.17A  | 373.01a | 341.34a | 245.31b | 319.89A |
| Mean        | 291.18A      | 289.12A      | 203.41B          |       | 291.75A      | 291.38A      | 200.06B         |       | 369.07A      | 360.83A      | 253.09B         | 362.72A  | 326.00A | 233.60B |

Means having the same alphabetical litter (s) are not significantly different at 0.05 level according to Duncan's multiple range test.

Table 10. Effect of regulated deficit irrigation (RDI) and ZnSO₄ NPs fertilization treatments on fruit length and width of "Nawomy" and "Sokary" mango cultivars during 2016 and 2017 seasons

| Zn T. (ppm) | "Nawomy" cv. | "Sokary" cv. | Fruit length (cm) | Mean | "Nawomy" cv. | "Sokary" cv. | Fruit width (cm) | Mean |
|-------------|--------------|--------------|------------------|------|--------------|--------------|-----------------|------|
| 100% of Etc | RDI-75% of Etc | RDI-50% of Etc | 100% of Etc | RDI-75% of Etc | RDI-50% of Etc | 100% of Etc | RDI-75% of Etc | RDI-50% of Etc | Mean |
| 0           | 10.19b       | 9.00c        | 8.93c            | 9.37C  | 9.65abc      | 9.93ab       | 8.85c           | 9.48A  | 7.65b        | 7.23c        | 7.05d         | 7.32B  | 7.60a       | 7.50ab       | 7.00b         | 7.37A |
| 50          | 10.89ab      | 10.83ab      | 9.00c            | 10.24B  | 10.32a       | 10.00ab      | 9.03bc          | 9.78A  | 8.17a        | 7.93ab       | 7.33bc        | 7.81AB | 7.80a       | 7.60a        | 7.00b         | 7.47A |
| 100         | 11.63a       | 11.45a       | 9.95bc           | 11.01A  | 10.50a       | 10.27a       | 9.07bc          | 9.95A  | 8.56a        | 8.23a        | 7.74b         | 8.18A  | 8.00a       | 7.85a        | 7.03b         | 7.63A |
| Mean        | 10.90A       | 10.43A       | 9.29B            |       | 10.16A       | 10.07A       | 8.98B           |       | 8.13 A       | 7.81AB       | 7.37B         | 7.80A  | 7.65A       | 7.01B         |                |

Means having the same alphabetical litter (s) are not significantly different at 0.05 level according to Duncan's multiple range test.
**Table 11. Effect of regulated deficit irrigation (RDI) and ZnSO₄ NPs fertilization treatments on TSS and total sugar of "Nawomy" and "Sokary" mango cultivars fruits during 2016 and 2017 seasons**

| Zn T. (ppm) | "Nawomy" cv. | "Sokary" cv. | Total sugars (%) |
|-------------|--------------|--------------|-----------------|
|             | TSS (%)      | TSS (%)      | TSS (%)         |
|             | RDI-75% of Etc | RDI-50% of Etc | Mean | RDI-75% of Etc | RDI-50% of Etc | Mean | RDI-75% of Etc | RDI-50% of Etc | Mean |
| 0           | 13.63C       | 10.72c       | 11.23C          |
| 50          | 14.11c       | 12.02c       | 12.42c          |
| 100         | 15.15A       | 12.47A       | 13.63A          |

Means having the same alphabetical litter (s) are not significantly different at 0.05 level according to Duncan's multiple range test.

**Table 12. Effect of regulated deficit irrigation (RDI) and ZnSO₄ NPs fertilization treatments on acidity and ascorbic acid of "Nawomy" and "Sokary" mango cultivars fruits during 2016 and 2017 seasons**

| Zn T. (ppm) | "Nawomy" cv. | "Sokary" cv. | Ascorbic acid (mg/100 g of fresh pulp) |
|-------------|--------------|--------------|--------------------------------------|
|             | Acidity (%)  | Acidity (%)  | RDI-75% of Etc | RDI-50% of Etc | Mean | RDI-75% of Etc | RDI-50% of Etc | Mean | RDI-75% of Etc | RDI-50% of Etc | Mean |
| 0           | 1.22A        | 1.27A        | 32.95cd         | 32.45d         | 32.93B |
| 50          | 1.29a        | 1.27A        | 34.82ab         | 33.11bcd       | 34.24A |
| 100         | 1.24A        | 1.27a        | 35.45a          | 33.47b         | 34.78A |

Means having the same alphabetical litter (s) are not significantly different at 0.05 level according to Duncan's multiple range test.
Conclusions

The amount of mango irrigation is important to improve the water-saving strategies for sustainable subtropical agriculture in orchard mango trees. In the Nawomy and Sokary mango trees studied, the highest yield and water-use efficiency were obtained with RDI-100% of ETc or RDI-75% of ETc treatment, and thus the RI-75% of ETc is a recommended irrigation treatment that save 25% of irrigation water. In addition, the average fruits weight and size, length and width were larger for mango from the 100% of ETc and RDI-75% of ETc, with TSS %, total reducing sugars and ascorbic acid content being significantly greater than fruit of other irrigation treatments. Also, the results of this research are due to the beneficial effects of nano zinc foliar spray treatments that enhanced the fruiting of Nawomy and Sokary mango trees and this may be reflect on enhancing nutrient use efficiency. It could be concluded that irrigated trees at RDI- 75% of ETc with foliar spraying of nano zinc (NPs-ZnSO₄ at 100 ppm) was the most effective treatment for increasing fruit set, total yield and physical and chemical characteristics of fruit as well as water use efficiency of Nawomy and Sokary mango trees.

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