

# Impact of different nano-forms of potassium on growth, yield and fruit quality of Zebda mango under deficit irrigation water strategy

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## Abstract

Irrigation water is a critical and key factor for the sustainable growing of mango in arid and semiarid regions. Thus, finding tools for saving irrigation water without harming productivity and the environment presents a major challenge for sustainable agriculture in this region. Therefore, this study aimed to evaluate the foliar application of nano potassium silicate (NPS), nano potassium citrate (NPC) and nano potassium nitrate (NPN) at concentrations of 0.1 and 0.2% during flower bud induction (mid-November), pre-flowering (mid-February), and full bloom (late March) on the growth and productivity of Zebda mango trees under different deficit irrigation regimes (100%, 85% and 70% of irrigation requirements, IR). The findings indicated that, decreasing IR from 100% to 70% IR resulted in control treatment a decline of 21.7% and 11.2% in the number of leaves, and a decrease of 24.5% and 27.63% in fruit set, for both seasons, respectively. Also, all Nano potassium forms enhanced vegetative growth and yield. NPS at 0.1% increased number of leaves by 7.38 and 19.85%, fruit set% by 13.88 and 42%, fruit weight by 3.37 and 3.73%, fruit number by 13.48 and 16% and yield by 16 and 19.4% compared to control for both seasons, respectively. Moreover, 0.1% NPS was effective in mitigate severe deficit irrigation (70% IR + 0.1% PNS) impacts by increasing number of leaves by 16.63 and 22.37%, fruit number by 9.46 and 8.72%, and yield by 9.7 and 9.2% for both seasons compared to 70% IR, respectively.

**Key words:** Mango (*Mangifera indica* L.), nano potassium, water stress, yield, TSS, leaf area

## Introduction

Mango (*Mangifera indica* L.) is a member of the Anacardaceae family, which possesses high nutritional value. Mangoes are abundant in many vitamins (A and C), sugars, carbohydrates, proteins, organic acids and minerals (Zafar and Sidhu, 2017). Also, it is rich in antioxidants (lutein, beta-carotene, phenolic compounds), which protect the body from free radicals and reduce the incidence of chronic diseases (Naliyadhara *et al.*, 2023). The cultivated mango lands are 2.5 million ha worldwide, with 56 million tons of fruit production (FAO, 2020). In Egypt, the mango cultivated area ranks third after grape and citrus, with 328284 fed and total production about 1429552 tons (Egyptian Ministry of Agriculture, 2023).

Under arid and semiarid areas, water availability is a critical factor and a significant challenge for plant development, making the optimization of water use vital for sustainability, finding applicable strategies that minimize water loss from soil evaporation or water leaching, as well as plant transpiration or leaching. The global population is projected to grow by up to 50% by 2025, which will increase demand for natural resources (water and soil) and require greater food production (FAO, 2021). So, sustained deficit irrigation (SDI) could be one of the actions to address the outlined challenge through different deficit irrigation strategies (Lipan *et al.*, 2021). Severe SDI decreased fruit yield in many mango cultivars, such as Zebda (Shaban *et al.*, 2025a, b) and Keitt (Shaban *et al.*, 2020; Shaban *et al.*, 2021).

Then, other horticultural practices must be applied to alleviate water shortages, such as shading (Shaban *et al.*, 2021) and soil conditioners (Shaban *et al.*, 2025a, b). Nanotechnology is another innovative technique that can mitigate the negative impact of deficit irrigation on plants.

Nanomaterials consist of very small particles (1-100 nm) with a high specific surface area, which confer distinct physicochemical properties. It is used in many applications, including environmental protection, medicine, and food and agriculture (Rashedy *et al.*, 2024). The application of nano-fertilizers enhances nutrient use efficiency, minimizing mineral overuse and soil toxicity (Naderi and Danesh-Shahraki, 2013). Nanoparticles are more effective and can be absorbed through the cuticle, ensuring controlled release and targeted delivery. Also, Nanoparticles can enhance physiological and biochemical indicators of plants, such as photosynthetic rate and nutrient absorption efficiency, and boost the plant's defense system (Verma *et al.*, 2022; Mahdy *et al.*, 2024).

Potassium (K) is an essential primary nutrient for plant productivity and fruit quality. It is involved in carbohydrate metabolism, activating numerous enzymes, and facilitating nutrient transport across membranes. Its lack negatively affects protein synthesis and photosynthesis, consequently restricting plant production. K supports the activation of many enzymes that play roles in chlorophyll maintenance, photosynthesis, ROS detoxification, and the plasma membrane ane (Hasanuzzaman

*et al.*, 2018). Also, K regulates photosynthesis and transpiration by modulating stomatal activity, maintaining turgor pressure, facilitating photophosphorylation, promoting the movement of photoassimilate products, and enhancing stress tolerance (Sanyal *et al.*, 2020).

Potassium silicate (PS) used as a fertilizer in numerous plants, providing the primary source of silicon (Si) and potassium (K). PS increased the levels of amino acids and sugars in plants, which improved fruit quality (Wu and Liu, 2007). Gad *et al.* (2021) reported that Nano potassium silicate (NPS) could enhance K and Si characteristics and provide various chemical-physical properties (surface area, positive nature, volume etc.). Nanoparticles (NPs) can easily penetrate plant tissues and influence various metabolic processes of the plant with their porous nature, which makes it as ideal NPs for different molecules working together (Rastogi *et al.*, 2019). Si is involved in activating many enzymes, ATP synthesis, and regulating water and gas exchange (Nido *et al.*, 2019). Potassium nitrate (PN) is an alternative source for K and nitrogen (N) which can improve plant tolerance to flooding and salt stress (Anjum, 2016).

Nano potassium (NK) alleviates water stress in many plants, such as date palm (Al-Saif *et al.*, 2023; Shareef *et al.*, 2021; Elkosary *et al.*, 2022), sweet orange (Manshad *et al.*, 2025), Washington navel orange (Al-Sabbagh *et al.*, 2024), and Flame Seedless grapevines (Hamza *et al.*, 2019). The goal of this study was to evaluate the effects of different sources of NK (citrate, acetate, nitrate) on vegetative growth and productivity of Zebda mango trees grown under a deficit irrigation strategy.

## Materials and methods

**Experimental details:** This experiment was carried out during two consecutive seasons (2020-2021 and 2021-2022) on 15-year-old Zebda mango trees. The trees were planted at 5 × 3 m in sandy soil under a drip irrigation system in the Agricultural Production and Research Station, National Research Centre, El-Emam Malek village, El-Behaira Governorate, Egypt (latitude 30.8667 N, and longitude 30.1667 E). All trees received the common horticultural practices.

**Experiment layout and treatments:** Sixty-three trees were chosen from the Zebda mango cv orchard for this experiment. The selected trees were arranged in 21 treatments with three trees for each treatment and each 1 tree was treated as a replicate. Selected trees received the one of the following treatments: 3

levels of irrigation requirements (100% IR, 85% IR and 70% IR) with foliar application of potassium nanoparticles (Potassium Silicate NPS (5% K and 10% Si) - Potassium Citrate NPC (20% K) - Potassium Nitrate NPN (20% K and 5% N)) 3 concentrations (0, 0.1 and 0.2%) in 3 times in November, beginning of season in mid-February and full bloom.

**Irrigation requirements:** IR were calculated according to Allen *et al.* (1998); the crop coefficient (Kc) and Penman-Monteith equation were used to compute the daily irrigation water requirements. The volume of irrigation water applied for the first season from 1/9/2020 to 30/8/2021 and the second season from 1/9/2021 to 30/8/2022 were calculated using Equation 1 and amounted to 4348 m<sup>3</sup> fed.<sup>-1</sup>/season and 4297 m<sup>3</sup> fed.<sup>-1</sup>/season, respectively.

$$IR = [ET_0 \times Kc] / E_i - R + LR$$

Where IR = irrigation requirements, Kc = crop factor (Allen *et al.*, 1998), E<sub>i</sub> = irrigation efficiency (assumed 90%), R, mm precipitation and ET<sub>0</sub> = reference evapotranspiration, mm/day (estimated from the Central Laboratory for Climate - Agricultural Research Centre Egyptian Ministry of Agriculture at El-Nubaryia farm and according to Penman-Monteith; The amount of water needed for salt leaching was determined as the ratio of irrigation water salinity to drainage water salinity, or LR, mm. There was a three-day interval between irrigations.

**Nano materials preparation:** All NK were purchased from Nanotech for Photo Electronics (Nanotech, Giza, Egypt). NK were manufactured according to the bottom-up method using an alkylation technique according to (Makvandi *et al.*, 2020). To determine NK size, the suspension of the “material” was sonicated for 25 minutes on an ultrasonicator (Crest Ultrasonics Corp., New Jersey, USA). Then, a few drops were loaded on a carbon-coated copper grid, left to dry. Finally, the grid loaded with the sample was examined by HR-TEM (JEOL, JEM-2100, Tokyo, Japan), operated at 200 kV (Fig. 1 A-C) (Ahmed *et al.*, 2025).

**Vegetative growth parameters:** Every year in March, 12 branches from 4 sides of the tree were randomly marked for measuring both vegetative and fruiting attributes. In August, shoot length was measured (cm) of new developed flushes per shoot, shoot diameter (cm) with caliper, number of leaves was enumerated and leaf area (cm<sup>2</sup>) was measured (30 leaves per treatment) using the following equation (Ahmed and Morsy 1999).

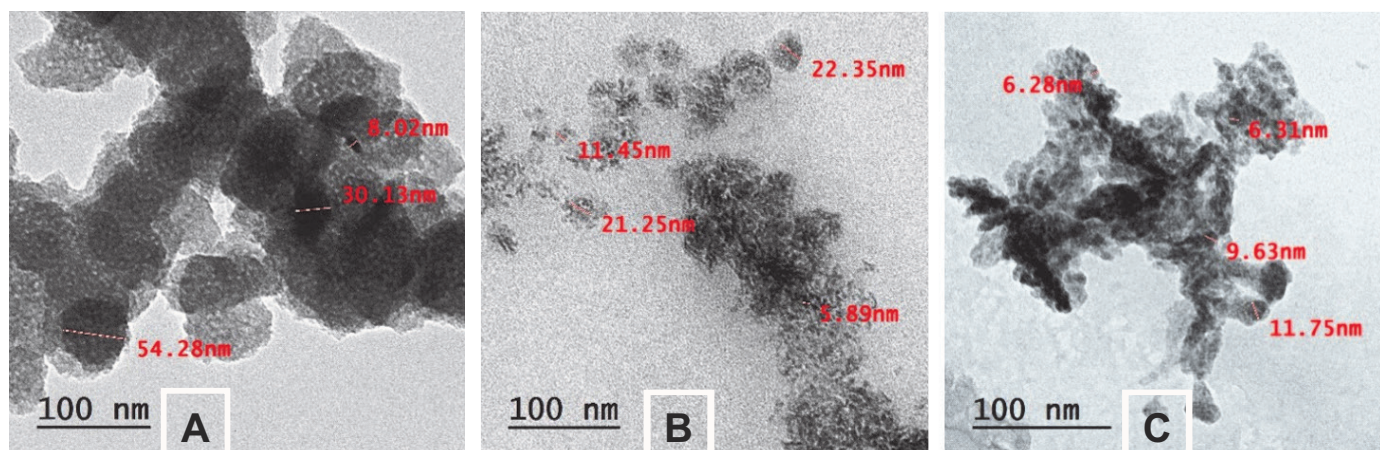


Fig. 1. Transmission electron microscope (TEM) of NPS: (A) Nano-Potassium Silicate, (B) Nano-Potassium Citrate, (C) Nano-Potassium Nitrate

Leaf area = 0.70 (leaf length × leaf width) + 1.06

**Flowering and fruiting characteristics:** Initial fruit set was determined by counting the number of setting fruits per panicle two weeks after petal fall for panicles on tagged shoots. Final fruit set was determined by counting the number of retained fruits per panicle at harvest (first week of August). Fruit drop% was determined at harvest by calculating final fruit set from initial fruit set, final fruit set, fruit drop and fruit retention as follows:

Initial fruit set (Number of fruitlets/ panicle) was determined as the number of fruitlets per panicle two weeks after petal fall for panicles on tagged shoots. Fruit drop% was determined at harvest as the following equation: (Initial fruit set - Final fruit set) ÷ Initial fruit set × 100. Number of fruits: was estimated by multiplying the number of fruits per tree at harvest time. Yield (kg) per feddan (4200 m<sup>2</sup>): was estimated by multiplying the number of trees per feddan by the average fruit weight per tree.

**Fruit physical and chemical characteristics:** A sample of 15 mature fruits from each replicate was taken at the harvest time according to (Abd El-Razek et al., 2013) for determining the physical and chemical properties.

Fruit weight was measured by a digital balance with 0.0001 g sensitivity. Fruit volume was measured by the water displacement method. The fruit total soluble solids (TSS) of mango fruit juice were measured using a digital refractometer (AOAC 1990). The total soluble solids were expressed as a percent.

**Statistical analysis:** The analysis of variance (ANOVA) was performed separately for each season using a split-block design, with irrigation levels in the main plot and nano potassium forms application in the sub-plot, following procedures reported by Gomez and Gomez (1984). Differences between the mean values of treatments were compared using the least significant difference (LSD) test at  $P = 0.05$ . Data were analyzed with ANOVA in the COSTAT software package (Snedecor and Cochran, 1989).

## Results and discussion

**Vegetative growth:** For the irrigation levels effects, shoot length, since 100% IR treatment recorded (21.66 and 25.60cm) which had the highest significant shoot length (Table 1) compared to IR at 70% (19.36 and 21.95 cm). For K application, NPS at 0.1% (22.53 and 27.45 cm) and NPC at 0.2% (20.54 and 27.04 cm) recorded the highest significant shoot length compared to the control (20.54 and 21.03 cm). The interaction effects revealed that, 100% IR+0.1% NPS recorded the highest significant shoot length (24.95 and 29.63 cm).

Regarding the impacts of NK and IR on shoot diameter (Table 2), 100% IR recorded the highest values (0.40 and 0.34 cm). Also, 0.1% NPS (0.35 and 0.47 cm) recorded the highest significant shoot diameter compared to the control (0.33 and 0.38 cm). For the interaction effects, 100% IR + 0.1% NPS showed the highest significant shoot diameter (0.45 and 0.64 cm).

For the impacts of NK and IR on the number of leaves of Zebda mango trees (Table 3), it can be noted that 100% IR (22.68 and 26.36) recorded the highest significant number of leaves compared to 70% IR (17.76 and 23.40). Also, 0.2% NPN (20.71 and 24.50) recorded the highest significant leaf area compared to

Table 1. Effect of different sources of nano-potassium on the shoot length of Zebda mango trees grown under deficit irrigation levels

Treatments	Shoot Length cm							
	Irrigation levels (%) (2021)				Irrigation levels (%) (2022)			
	100	85	70	Mean	100	85	70	Mean
Control	19.97	21.54	19.37	20.29	19.97	22.86	21.13	21.32
0.1% NPS	24.95	23.45	19.19	22.53	29.63	24.97	27.74	27.45
0.2% NPS	23.29	20.34	17.53	20.39	24.63	22.97	21.52	23.04
0.1% NPC	20.99	21.14	19.19	20.44	27.19	26.97	17.41	23.86
0.2% NPC	22.22	22.07	17.34	20.54	26.41	27.30	27.41	27.04
0.1% NPN	20.18	21.94	22.06	21.39	24.08	27.86	21.13	24.36
0.2% NPN	20.04	17.82	20.86	19.57	27.30	20.86	17.30	21.82
Mean	21.66	21.19	19.36		25.60	24.82	21.95	
LSD 5%	Irrigation level(A)=1.24 Potassium level (B)=1.27 AxB= 2.31				Irrigation level(A)= 3.16 Potassium level (B)=5.87 AxB=6.94			

Table 2. Effect of different sources of nano-potassium on the shoot diameter of Zebda mango trees grown under deficit irrigation levels

Treatments	Shoot diameter cm							
	Irrigation levels (%) (2021)				Irrigation levels (%) (2022)			
	100	85	70	Mean	100	85	70	Mean
Control	0.36	0.33	0.31	0.33	0.36	0.36	0.41	0.38
0.1% NPS	0.45	0.32	0.29	0.35	0.64	0.41	0.37	0.47
0.2% NPS	0.44	0.27	0.38	0.36	0.36	0.35	0.42	0.38
0.1% NPC	0.38	0.38	0.35	0.37	0.36	0.35	0.47	0.39
0.2% NPC	0.31	0.34	0.38	0.34	0.40	0.39	0.44	0.41
0.1% NPN	0.41	0.34	0.33	0.36	0.44	0.36	0.38	0.39
0.2% NPN	0.42	0.33	0.32	0.36	0.44	0.44	0.35	0.41
Mean	0.40	0.33	0.34		0.43	0.38	0.41	
LSD 5%	Irrigation level(A)=0.03 Potassium level (B)=0.04 AxB=0.06				Irrigation level(A)=0.98 Potassium level (B)=1.22 AxB=2.00			

the control (19.51 and 22.56). For the interaction effects, 100% IR + 0.1% NPS (24.37 and 30) recorded the highest leaf number.

Leaf area did not differ significantly across irrigation levels, NK levels, or their interaction (Table 4). Keshk *et al.* (2023) previously reported increased vegetative growth due to K treatments, finding that K forms improved average leaf area and shoot length of Naomi mango cv. Also, Saady et. al. (2024) reported that spraying a mixture of fulvic acid (1%) and potassium citrate (1%) three times (growth stage, fruit setting stage, after one month later) improves vegetative growth of Zebda mango trees. Moreover, Ahmed *et al.* (2025) reported that K-citrate (1.5

Table 3. Effect of different sources of nano-potassium on the number of leaves of Zebda mango trees grown under deficit irrigation levels

Treatments	Number of Leaves							
	Irrigation levels (%) (2021)				Irrigation levels (%) (2022)			
	100	85	70	Mean	100	85	70	Mean
Control	22.16	19.44	16.92	19.51	18.89	26.56	22.22	22.56
0.1% NPS	24.37	22.32	16.17	20.95	30.00	29.89	21.22	27.04
0.2% NPS	21.71	19.01	23.00	21.24	26.67	24.67	23.22	24.85
0.1% NPC	23.84	18.34	17.33	19.84	27.00	22.67	20.00	23.22
0.2% NPC	23.16	22.43	17.25	20.95	24.44	27.33	26.67	26.15
0.1% NPN	20.92	22.28	14.81	19.34	28.50	28.44	23.56	26.83
0.2% NPN	22.58	20.71	18.83	20.71	29.00	29.00	26.89	28.30
Mean	22.68	20.65	17.76		26.36	26.94	23.40	
LSD 5%	Irrigation level (A)=0.03 Potassium level (B)=0.04 AxB= 0.06				Irrigation level(A)= 0.98 Potassium level (B)=1.22 AxB=2.00			

Table 4. Effect of different sources of nano-potassium on the leaf area of Zebda mango trees grown under deficit irrigation levels

Treatments	Leaf Area cm <sup>2</sup>							
	Irrigation levels (%) (2021)				Irrigation levels (%) (2022)			
	100	85	70	Mean	100	85	70	Mean
Control	69.04	71.70	56.17	65.64	71.27	77.12	71.39	73.26
0.1% NPS	79.82	73.27	72.53	75.21	86.52	75.47	77.01	79.67
0.2% NPS	69.05	77.79	55.29	67.38	83.08	80.91	76.19	80.06
0.1% NPC	74.91	69.15	61.70	68.59	74.76	77.73	82.42	78.30
0.2% NPC	66.51	69.74	66.40	67.55	72.25	85.65	77.48	78.46
0.1% NPN	72.58	72.84	66.93	70.78	73.67	79.55	76.53	76.58
0.2% NPN	65.20	76.65	59.97	67.27	70.70	86.17	78.62	74.66
Mean	71.02	73.02	62.71		77.00	80.37	77.09	
LSD 5%	Irrigation level(A)=NS Potassium level (B)=NS AxB=11.6661				Irrigation level(A)=NS Potassium level (B)=NS AxB=12.559			

mL/L) improved vegetative growth of Keitt mango trees.

Decreasing irrigation levels led to a reduction in vegetative growth of many fruit trees like grape (Fayek *et al.*, 2022c), pomegranate (Fayek *et al.*, 2022a and b) and many of mango cultivars such as Keitt (Shaban *et al.*, 2020; Shaban *et al.*, 2021); Zebda (Shaban *et al.*, 2025a; Shaban *et al.*, 2025b). Also, Si treatments succeeded in improving vegetative growth under water stress in sweet pepper (Tantawy *et al.*, 2015). Moreover, spraying chitosan and Nano potassium silicate (0.6 and 0.8 g/L) on 15 February (before the flowering stage) increased the leaf area of Zebda and Ewasy mango trees (Alwea *et al.*, 2018). Spraying Keitt mango with potassium nitrate (2%) and zinc sulfate (200 ppm) increased shoot length and leaf area (Aly *et al.*, 2019). Foliar application of KNO<sub>3</sub> was applied one month before (December) and one month after (February) the normal flowering, improving vegetative growth of mango cv. Spraying Nano Si (110 ppm) + Nano Zn (110 ppm) at 50% flowering increased the leaf area of Alphonse mango trees (Gad-Elkarim *et al.*, 2023). (Hamza *et al.*, 2019) reported that the foliar nano-chitosan potassium fertilizer (250, 500, 1000 ppm) combined with different soil potassium sulfate rates (50%, 75%, and 100% of the recommended dose) resulted in nano-K treatments significantly increasing shoot length, diameter, and leaf area compared with the control. On Ewais mango, (Elsheery *et al.*, 2020) evaluated the effects of foliar application of zinc oxide (nZnO) and silicon (nSi) nanoparticles under salinity stress, the treatments included nZnO (50, 100, 150 mg/L), nSi (150, 300 mg/L), and their combinations, and they found the combination of 100 mg/L nZnO + 150 mg/L nSi significantly enhanced leaf area.

**Flowering:** With regard to the impacts of NK and IR on initial fruit set (Table 5), it can be seen that 100% IR recorded the highest significant initial fruit set percentage (5.59, 5.97) compared to 70% IR (4.22, 4.32%). Also, 0.1% NPS (5.33 and 6.32%) recorded the highest significant initial fruit set compared to the control (4.68 and 4.45%). For the interaction effects, 100% IR + 0.1% NPS had the highest initial fruit set percentage (6.03% and 7%) in both seasons.

Deficit irrigation reduced initial and final fruit set in Keitt (Shaban *et al.*, 2020; Shaban *et al.*, 2021) and Zebda mango trees (Shaban *et al.*, 2025a; Shaban *et al.*, 2025b). Spraying NPS at 0.6 and 0.8 g/L increased panicle length, initial and final fruit set, while it decreased floral malformation of Ewais mango cultivar (Gad *et al.*, 2021). A combination of potassium silicate at 2 mL/L and nano NPK at 4 g/L improved fruit set of both Khadhrawi and Khastawi

Table 5. Effect of different sources of nano-potassium on the Initial fruit set in Zebda mango trees grown under deficit irrigation levels

Treatments	Initial Fruit set %							
	Irrigation levels (%) (2021)				Irrigation levels (%) (2022)			
	100	85	70	Means	100	85	70	Means
Control	5.17	5.10	3.77	4.68	5.72	5.10	2.52	4.45
0.1% NPS	6.03	5.40	4.57	5.33	7.00	6.64	5.32	6.32
0.2% NPS	5.70	5.30	4.53	5.18	6.18	5.48	3.83	5.16
0.1% NPC	5.73	5.20	4.23	5.05	5.26	4.35	5.14	4.92
0.2% NPC	5.63	5.10	4.37	5.03	6.22	4.41	4.78	5.14
0.1% NPN	5.57	5.13	4.20	4.97	5.51	4.43	4.83	4.92
0.2% NPN	5.33	4.93	3.87	4.71	5.91	4.36	3.80	4.69
Mean	5.59	5.17	4.22		5.97	4.97	4.32	
LSD 5%	Irrigation level(A)=0.57 Potassium level (B)=0.33 AxB=0.629				Irrigation level(A)=0.83 Potassium level (B)=0.94 AxB=1.44			

date palm (Al-Khafaji and Al-Amri, 2025).

Concerning the effect of NK and IR on fruit drop of Zebda mango trees (Table 6), it can be concluded that, 100% IR had the lowest fruit drop (77.34, 76.10%) in both seasons, while, 70% IR (80, 79.16%) recorded the highest fruit drop without significant differences. Also, 0.1% NPS recorded the lowest fruit drop percentage (79.35 and 76.73%) without significant differences. For the interaction effects, 100% IR + 0.1% NPS (75.62% and 69.45%) recorded the lowest fruit drop. Under severe deficit irrigation (70% IR) NPS at 0.2% recorded the lowest fruit drop% (77.6 and 75.83%) compared to 70% IR (78.66 and 81.21%).

Table 6. Effect of different sources of nano-potassium on the fruit drop percentage of Zebda mango trees grown under deficit irrigation levels

Treatments	Fruit drop %							
	Irrigation levels (%) (2021)				Irrigation levels (%) (2022)			
	100	85	70	Means	100	85	70	Means
Control	76.60	80.74	78.66	78.67	75.99	83.65	81.21	80.28
0.1% NPS	75.62	81.39	81.03	79.35	69.45	83.47	77.27	76.73
0.2% NPS	78.34	81.28	77.60	79.07	80.05	83.49	75.83	79.79
0.1% NPC	77.85	81.40	80.32	79.86	70.05	79.35	82.05	77.15
0.2% NPC	76.85	83.64	80.11	80.20	75.49	84.38	81.38	80.42
0.1% NPN	77.91	81.81	82.07	80.60	76.93	79.07	83.94	79.98
0.2% NPN	78.22	83.63	80.18	80.68	84.75	87.19	84.21	85.38
Mean	77.34	81.98	80.00		76.10	82.94	79.16	
LSD 5%	Irrigation level(A)=3.65 Potassium level (B)=2.18 AxB=4.80				Irrigation level(A)=5.29 Potassium level (B)=4.21 AxB=6.91			

Regarding the impacts of NK and IR on the number of Zebda mango fruit per tree (Table 7), it can be noted that 100% IR recorded the highest significant number of fruits (56.51) compared to 70% IR (40.33) in the first season. For NK impact, 0.1% NPS recorded the highest significant number of fruit (51.70 and 58.78), while control treatment recorded the lowest values (45.56 and 50.67). For the interaction effect, 0.1% NPS+100% IR recorded the highest fruit number (62.11 and 65.67).

Regarding the impacts of NK and IR on Zebda mango fruit weight (Table 8), it can be noted that 100% IR recorded the highest significant fruit weight (459.36 and 466.24 g) compared to 70% IR (421.66 and 465.93 g) in the first season. For NK impact, 0.1% NPS recorded the highest significant fruit weight (51.70 and 58.78 g), while the control treatment recorded the lowest values (45.56 and 50.67 g). For the interaction effect, 0.1% NPS+100% IR recorded the highest fruit weight (62.11 and 65.67 g) with a

Table 7. Effect of different sources of nano-potassium on the number of fruit per tree of Zebda mango trees grown under deficit irrigation levels

Treatments	Number of fruit per tree							
	Irrigation levels (%) (2021)				Irrigation levels (%) (2022)			
	100	85	70	Means	100	85	70	Means
Control	47.00	51.00	38.67	45.56	51.67	50.67	49.67	50.67
0.1% NPS	62.11	50.67	42.33	51.70	65.67	56.67	54.00	58.78
0.2% NPS	53.00	50.33	41.67	48.33	61.33	50.00	59.33	56.89
0.1% NPC	58.33	51.67	40.67	50.22	55.00	50.56	52.00	52.52
0.2% NPC	55.67	48.67	41.00	48.45	61.33	63.22	63.00	62.52
0.1% NPN	61.22	50.33	40.67	50.74	54.67	56.33	50.11	53.70
0.2% NPN	58.22	44.33	37.33	46.63	59.67	59.11	52.67	57.15
Mean	56.51	49.57	40.33		58.48	55.22	54.40	
LSD 5%	Irrigation level(A)=3.27 Potassium level (B)=4.15 AxB=5.95				Irrigation level(A)=4.65 Potassium level (B)=5.55 AxB=10.86			

significant value in the first season. For NK impact, 0.1% NPS recorded the highest significant fruit weight (439.21 & 468.33 g), while control treatment recorded the lowest values (424.90 g) in first season. For the interaction effect, 0.1% NPS+100% IR recorded the highest fruit weight (474.19 & 484.44 g) with a significant value in the first season.

Similarly, on “Kensington Pride” mango cv. Irrigated with deficit water during flowering and fruit set reduced mango fruit growth and size (Simmons *et al.*, 1995). In addition, Baiea *et al.* (2015) studied the effects of applying different forms of potassium. They recorded that using 2% mono potassium phosphate, 2% di-potassium phosphate, and 2% potassium nitrate to Hindi mango trees four times during full bloom, after fruit set, during fruit growth, and before harvesting was highly effective in improving fruit retention.

Decreasing IR reduced fruit number. Characteristics such as maximum fruit retention and total fruits per tree under control. Overall, the combined NPK application was the most effective in improving fruiting, yield, physiochemical traits, and overall fruit quality of mango trees (Azam *et al.*, 2020). Reducing irrigation water from 100% to 70% decreased fruit weight, number, and yield of Keitt (Shaban *et al.*, 2020; Shaban *et al.*, 2021) and Zebda mango (Shaban *et al.*, 2025a; Shaban *et al.*, 2025b). A combination of potassium silicate at 2 mL/L and nano NPK at 4 g/L increased fruit number and yield of both Khadhrawi and Khastawi date palm (Al-Khafaji and Al-Amri, 2025). Also, Gad *et al.* (2021) reported that Nano-potassium silicate at 0.8 g/L resulted in the highest fruit yield for Ewais mango trees. KNO<sub>3</sub>

Table 8. Effect of different sources of nano-potassium on the fruit weight of Zebda mango trees grown under deficit irrigation levels

Treatments	Fruit weight (g)							
	Irrigation levels (%) (2021)				Irrigation levels (%) (2022)			
	100	85	70	Means	100	85	70	Means
Control	448.33	417.44	408.92	424.90	477.67	425.87	450.89	451.48
0.1% NPS	474.19	434.71	408.72	439.21	484.44	437.87	482.67	468.33
0.2% NPS	456.59	439.37	410.40	435.45	454.81	441.85	477.44	458.03
0.1% NPC	445.78	435.34	433.88	438.33	461.89	445.44	468.11	458.48
0.2% NPC	456.33	429.06	429.29	438.23	470.00	413.42	467.93	450.45
0.1% NPN	466.33	421.53	408.00	431.95	460.89	434.05	466.33	453.76
0.2% NPN	468.00	422.21	452.39	447.53	453.99	423.71	448.15	441.95
Mean	459.36	428.52	421.66		466.24	431.74	465.93	
LSD 5%	Irrigation level(A)=2.57 Potassium level (B)=9.53 AxB=10.36				Irrigation level(A)= 3.93 Potassium level (B)=10.23 AxB=11.16			

at 2%+ ZnSO<sub>4</sub> at 200 ppm improved fruit weight, number of ‘keitte’ mango trees (Aly *et al.*, 2019). Alwea *et al.* (2018) reported that Zebda and Ewasy treated with nano-silica at 0.6 and 0.8 g/L improved. Also, Saady *et al.* (2024) reported that spraying a mixture of fulvic acid (1%) and potassium citrate (1%) three times (at the growth stage, at the fruit-setting stage, and 1 month later) improves vegetative growth of Zebda mango trees. Moreover, Ahmed *et al.*, (2025) reported that K-citrate (1.5 ml/L) improved vegetative growth of Keitt mango trees. More recently, spraying Nano Si (110 ppm) + Nano Zn (110 ppm) at 50% flowering increased fruit set, leaf area, fruit weight and fruit yield of Alphonse mango trees (Gad-Elkarim *et al.*, 2023).

**Fruit yield and components:** Regarding the impacts of NK and IR on fruit yield (Table 9) per feddan, it can be noted that 100% IR recorded the highest significant fruit yield (6.52 and 6.79 tons) compared to 70% IR (4.42 and 6.59 tons). For NK impact, 0.1% NPS recorded the highest significant fruit yield (5.94 and 7.05 tons), while the control treatment recorded the lowest values (5.12 and 5.90 tons). For the interaction effect, 0.1% NPS+100% IR recorded the highest significant fruit yield (7.50 and 7.68 tons) with a significant value in the first season.

Table 9. Effect of different sources of nano-potassium on yield (ton) per feddan of Zebda mango trees grown under deficit irrigation levels

Treatments	Yield ton/fed.							
	Irrigation levels (%) (2021)				Irrigation levels (%) (2022)			
	100	85	70	Means	100	85	70	Means
Control	5.61	5.65	4.11	5.12	5.47	6.08	6.14	5.90
0.1% NPS	7.50	5.82	4.51	5.94	7.68	7.06	6.40	7.05
0.2% NPS	6.93	5.73	4.43	5.70	6.11	6.26	7.44	6.60
0.1% NPC	6.22	5.98	4.60	5.60	7.37	6.17	6.25	6.60
0.2% NPC	6.84	5.23	4.57	5.55	6.60	7.00	7.69	7.10
0.1% NPN	5.99	5.68	4.32	5.33	7.43	6.84	6.02	6.76
0.2% NPN	6.55	4.89	4.39	5.28	6.88	6.89	6.19	6.65
Mean	6.52	5.57	4.42		6.79	6.08	6.14	
LSD 5%	Irrigation level(A)=0.35 Potassium level (B)=0.63 AxB=1.05				Irrigation level(A)= 0.56 Potassium level (B)=0.99 AxB=1.02			

Al-Khafaji and Al-Amri (2025) reported that combining potassium silicate foliar sprays with nano-fertilizers can significantly increase date productivity and fruit quality. The same results were reported by Gad *et al.* (2021), who found that NPS at 0.8 g/L was more effective at enhancing mango fruit yield. Additionally, fruit yield per tree and fruit quality parameters were all significantly improved when Keitt mango trees were sprayed five times with a solution of 2% potassium nitrate and 200 ppm boric acid (Aly *et al.*, 2019).

Regarding the impacts of NK and IR on fruit TSS content (Table 10), it can be noted that 70% IR increased fruit TSS (11.08 and 12.06 Brix) compared to 100% IR (10.76 and 11.95 Brix) without significant differences. For NK impact, 0.1% NPS recorded the highest fruit TSS (11.11 and 13.47 Brix) with a significant value in the second season compared to the control, which recorded the lowest values (10.33 and 11.37 Brix). For the interaction effect, 0.1% NPS+100% IR recorded the highest significant fruit yield (12.67 and 14.73 Brix) compared to 100% IR without NK (8.33 and 10.40 Brix).

Data presented in Table 11 showed that fruit volume (cm<sup>3</sup>) was highest with 100% IR (436.11 and 481.38 cm<sup>3</sup>), while 70% IR recorded the lowest fruit volume (428.14 and 474.02 cm<sup>3</sup>).

Table 10: Effect of different sources of nano-potassium on TSS content of Zebda mango fruits grown under deficit irrigation levels

Treatments	Fruit TSS (Brix) content							
	Irrigation levels (%) (2021)				Irrigation levels (%) (2022)			
	100	85	70	Means	100	85	70	Means
Control	8.33	11.33	11.33	10.33	10.40	11.44	12.27	11.37
0.1% NPS	12.67	10.22	10.44	11.11	14.73	13.56	12.13	13.47
0.2% NPS	12.00	10.33	10.00	10.78	13.24	12.67	11.73	12.55
0.1% NPC	9.44	10.33	11.22	10.33	11.93	12.30	11.44	11.89
0.2% NPC	10.56	10.78	11.67	11.00	10.91	14.17	11.40	12.16
0.1% NPN	10.33	10.44	11.89	10.89	9.33	12.91	12.87	11.70
0.2% NPN	12.00	11.11	11.00	11.37	13.11	12.16	12.55	12.61
Mean	10.76	10.65	11.08		11.95	12.74	12.06	
LSD 5%	Irrigation level(A)=1.37 Potassium level (B)=1.57 AxB= 2.27				Irrigation level(A)= 2.22 Potassium level (B)=1.71 AxB=3.15			

Regarding the effect of NK, 0.1% NPS showed the highest significant fruit volume (445.90 and 481.86 cm<sup>3</sup>) compared to the control (425.49 and 465 cm<sup>3</sup>). For the interaction effect, 100% IR+ 0.1% NPS (451.73 and 493.70 cm<sup>3</sup>) compared to 100% IR without NK (426.89 and 476.30 cm<sup>3</sup>). Under severe deficit irrigation (70% IR), 0.2% NPN (461.14 and 472.22 cm<sup>3</sup>), 0.1% NPS (442.68 and 474.30 cm<sup>3</sup>), then 0.2% NPS (420.3, 484.93 cm<sup>3</sup>) increased fruit volume by 10.9 and 1.98%, 6.5 and 2.4% and 1.08 and 4.7%, respectively.

Table 11. Effect of different sources of nano-potassium on the of fruit volume of Zebda mango fruit grown under deficit irrigation levels

Treatments	Fruit volume cm <sup>3</sup>							
	Irrigation levels (%) (2021)				Irrigation levels (%) (2022)			
	100	85	70	Means	100	85	70	Means
Control	426.89	433.96	415.63	425.49	476.30	455.67	463.04	465.00
0.1% NPS	451.73	443.30	442.68	445.90	493.70	477.59	474.30	481.86
0.2% NPS	437.93	441.51	420.13	433.19	482.67	452.00	484.93	473.20
0.1% NPC	438.56	448.94	415.50	434.33	491.33	480.26	477.56	483.05
0.2% NPC	428.78	431.36	433.08	431.07	472.26	464.00	464.81	467.02
0.1% NPN	436.54	433.77	408.85	426.39	480.78	475.11	481.26	479.05
0.2% NPN	432.35	421.39	461.14	438.29	472.59	481.63	472.22	475.48
Mean	436.11	436.32	428.14		481.38	469.47	474.02	
LSD 5%	Irrigation level(A)=0.09 Potassium level (B)=0.27 AxB= 0.41				Irrigation level(A)= 0.14 Potassium level (B)=0.19 AxB=0.49			

Saad et al. (2024) showed the same results when spraying potassium on Zebda mango. Alwea et al. (2018) recorded that trees sprayed with nano-silica at 0.6 and 0.8 g/L demonstrated the highest average weight, length, and volume of mango fruits. In addition, Gad et al. (2021) reported that Spraying Nano-potassium silicate was more effective in improving fruit characteristics than untreated trees. Al-Khafaji and Al-Amri (2025) recorded that the combination of nano-NPK at 4 g/L and potassium silicate at 2 mL/L (N3S2) yielded the best results for most characteristics. These findings show that, in arid environments, using potassium silicate foliar sprays along with nano-fertilizers can significantly boost date productivity and fruit quality.

Irrigation water is essential for sustainable mango cultivation in arid and semiarid regions. This study aimed to assess the effectiveness of Nano potassium citrate (NPC), Nano potassium nitrate (NPN), and Nano potassium silicate (NPS) at concentrations of 0.1% and 0.2% during flower bud induction, pre-flowering, and full bloom under varying deficit irrigation rates (100%IR, 85%IR, 70%IR). Results showed that reducing irrigation from 100% to 70%IR led to a 21.7%

and 11.2% reduction in leaf count and a 24.5% and 27.63% drop in fruit set across two seasons. All Nano potassium treatments improved growth and yield, with 0.1% NPS showing notable increases in leaf number, fruit set, weight, count, and overall yield compared to controls. Moreover, NPS significantly mitigated the adverse effects of severe irrigation deficit, proving more effective than NPC and NPN in enhancing mango productivity.

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