Indian Journal of Agricultural Sciences **92** (9): 1061–1065, September 2022/Article
https://doi.org/10.56093/ijas.v92i8.106566

Zinc fertigation studies in Nagpur mandarin (*Citrus reticulata*) grown on black clay soil

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Received: 26 October 2020; Accepted: 8 July 2022

ABSTRACT

A field experiment was conducted for four seasons (2013–17) on 12-year-old bearing Nagpur mandarin (*Citrus reticulata* Blanco) plants budded on rough lemon rootstock (*Citrus jambhiri* Lush) at ICAR-Central Citrus Research Institute, Nagpur, Maharashtra. Six zinc-based treatments, viz. S_{100} as soil application of $ZnSO_4$ (100 g/plant), S_{200} as soil application of $ZnSO_4$ (200 g/plant), S_{300} as soil application of $ZnSO_4$ (300 g/plant, F_{100} as fertigation of $ZnSO_4$ (100 g/plant), F_{200} as fertigation of $ZnSO_4$ (200 g/plant) and F_{300} as fertigation of $ZnSO_4$ (300 g/plant) with uniform doses of macronutrients (450 g N + 150 g P_2O_5 + 150 K_2O/tree/year) were evaluated in a randomized block design (RBD) with four replications on a smectite rich alkaline black clay soil. Significantly higher concentration of Zn in index leaves was observed with fertigation treatments than soil application treatments with regard to fruit yield and quality. The fruit yield was observed significantly lower with soil application of $ZnSO_4$ (11.5–13.95 tonnes/ha with S_{100}-S_{300}) than fertigation treatments (15.6–16.4 tonnes/ha with F_{100}-F_{300}). The fruit quality parameters were observed much higher with F_{200} followed by F_{300}. On the other hand, the lowest acidity (0.82%) and higher TSS to acidity ratio (11.52) were observed with F_{200}. Hence, the treatment F_{200}, split through 4 pulses at 40 days interval from anthesis to the fruit development stage proved highly efficient for quality production of Nagpur mandarin in central India.

Keywords: Clay soil, Fertigation, Fruit yield, Nagpur mandarin, Quality, Soil application

Nagpur mandarin (*Citrus reticulata* Blanco) is a highly nutrient responsive crop (Srivastava and Singh 2003, 2008), with very common deficiency of zinc in bearing citrus orchards affecting both fruit yield and fruit quality fruit quality (Srivastava and Singh 2004), besides productive life of orchards (Srivastava and Singh 2005, 2009). The conventional method associated with zinc application through soil application is frequently associated with production of poor quality of mandarin fruits (Srivastava and Singh 2005, 2009). Presently, the fertilizer dose of macronutrients split into three doses and given in June, October and February (Srivastava and Malhotra 2014) has been observed highly responsive (Srivastava and Singh 2005, Srivastava and Malhotra 2017). Adoption of the micro-irrigation system and fertigation has shown clear cut advantages over surface irrigation methods and application of water and fertilizers together (Shirgure 2012).

Citrus growers in India are highly encouraged towards mass scale adopting of drip irrigation system with fertigation. But, micronutrient fertigation is still far from popular practice, with the result, growers have to resort to foliar application, without much incentive on growth, fruit yield and different fruit quality parameters (Shirgure 2013), besides involving frequent application with variable responses. It is, therefore, highly important to provide the correct amount of water and nutrients through micro-irrigation system at different growth stages in order to enhance the growth and uniformity of fruits coupled with a net harvestable yield of citrus cultivars (Shirgure *et al.* 2013, 2014). The studies in the past showed good response of fertigation in commercial citrus cultivars such as Shamouti sweet orange (Bielori 1984), Valencia orange (Koo and Smjastrala 1984), Sunburst mandarin (Ferguson *et al.* 1990), Nagpur mandarin (Shirgure *et al.* 2001), and acid lime (Shirgure *et al.* 2003. Imbibing clues from these successes, the concept of micronutrient fertigation fulfilling the zinc requirement right from flower initiation to fruit maturity was carried out to standardize the dose and schedule of zinc fertigation in with reference to response on plant growth, leaf nutrients concentration, fruit yield and quality of Nagpur mandarin, commercially grown in central India.

MATERIALS AND METHODS

A field experiment was conducted during 2013–17 at experimental farm of ICAR-Central Citrus Research

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Institute, Nagpur, Maharashtra on 12-year-old bearing Nagpur mandarin orchard propagated on rough lemon rootstock (*Citrus jambhiri* Lush) spaced at 6 m × 6 m on somectite rich black clay soil. The field trial consisted of six treatments, viz. soil application of $ZnSO_4$ (100 g/plant, S_{100}); soil application of $ZnSO_4$ (200 g/plant, S_{200}); soil application of $ZnSO_4$ (300 g/plant, S_{300}); fertigation of $ZnSO_4$ (100 g/plant, F_{100}); fertigation of $ZnSO_4$ (200 g/plant, F_{200}) and fertigation of $ZnSO_4$ (300 g/plant, F_{300}) in a randomized block design (RBD) with four replications. The texture of the soil was clay loam with 54 cm depth. Soil moisture content at field capacity and permanent wilting point was observed at 31.23% and 20.15%, respectively, with available water holding of the soil as 15.81 cm/m depth of soil.

The circular ring method (matching with pattern of feeder root distribution) was followed for fertilizer application under treatments involving soil application. The mandarin plants were irrigated with 8 lph drippers (3/plant) arrangement under a drip system using the daily water requirement of plants based on pan evaporation based irrigation schedules (0.8 Epan) during the non-rainy months (Shirgure and Srivastava 2018). The recommended doses of macronutrients dose given was given to bearing Nagpur mandarin through fertigation was supplied as (500 N:150 P_2O_5:150 K_2O g/plant) uniform application in all the treatments. Zinc fertigation started from January and continued will full fruit size development in as many 4 instalments at an interval of 40 days. The first dose of $ZnSO_4$ was given at 40 days after anthesis (18 February) as the stress was given in December and flowering initiated in January. The second dose of fertigation was given 80 days after flowering (20 March) representing pea size of fruits. The subsequent dose of $ZnSO_4$ fertigation was given at 120 days after flowering when the fruit was of marble size (30^{th}April). The fourth and last dose was given at 160 days from flowering on 10^{th}June, coinciding with peak fruit development stage and thereafter, no fertilizer application was made on the premise that the major nutrient demand for zinc ceases thereafter. The other cultural operations and plant protection measures were applied uniformly. All the NPK and $FeSO_4$ fertilizers were given from January and continued till June. While, the soil application of $ZnSO_4$ micronutrient was given in the two equal splits. The 50% dose of $ZnSO_4$ as per the treatments was applied in December and remaining 50% in June before initiation of monsoon.

Samples collection and analysis: The biometric parameters of Nagpur mandarin plants, viz. plant canopy volume (expressed as 0.524 HD^2 where H and D stand for plant height and canopy diameter, respectively), fruit yield record and quality analysis (Castle 1982, Ranganna 1986) were carried out annually to assess the cumulative effect of Zn based treatments. The leaf (6–7 month old leaves from non-fruiting terminals, covering 10% trees with 50–70 leaves) and soil samples (0–20 cm soil depth coinciding with below the drippers and between the drippers, later mixed together to make it representative of zone of maximum feeder root concentration as crop feeder soil zone) were collected from various treatments following standard procedures of leaf and soil sampling methods proposed by Srivastava *et al.*(2001). The leaf samples were digested in tri-acid mixture of HNO_3:H_2SO_4:$HClO_4$ in 2.5:1 ratio. The leaf N was determined using alkaline permanganate steam distillation method, P colorimetric method and K flame photometrically. The micronutrient analysis for Fe, Mn, Cu and Zn was carried on atomic absorption spectrophotometer for both leaf and soil samples. The data on growth, fruit yield and quality attributes generated for 4 years were statistically analyzed using analysis of variance as suggested by Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Response on leaf nutrient composition: Effect of differential doses of $ZnSO_4$ as soil application or fertigation showed a significant change in concentration of different macronutrients, including leaf Zn status (Table 1). However, the fertigation treatment F_{200} recorded highest concentration of macronutrients compared to rest of the other treatments, either at an equivalent rate of S_{200} or at higher doses of S_{300} in comparison to S_{100} being least effective of all. The leaf Cu content showed no significant response, either through a soil application or fertigation. While, fertigation treatment as F_{300} recorded the highest concentration of Fe and Mn content compared to rest of the other treatments (Table 1). Similarly, leaf Mn concentration either within fertigation treatments or soil application treatments, displayed a significant response with F_{200} surpassing all other treatments. In lieu of these accruing fertigation responses on leaf nutrients composition, it is still debatable to float a different leaf analysis based nutrient standards. We shall need to develop a different leaf nutrient standards under fertigation *vis-a-vis* soil fertilization?

These results with regard to plant available nutrients showed an altogether different pattern of response. Zinc fertigation treatments (F_{100}–F_{300}) irrespective of doses were statistically superior over soil application method (S_{100}–S_{300}). The treatment S_{200} showed highest content of available P and Zn than rest of the other treatments, while, available N, K, Fe and Cu were observed highest with treatment F_{300}. Plant available N and K were observed significantly higher with treatment F_{300}, with statistical on par response of F_{200} treatment. The lowest value of plant available Fe and Zn were recorded with S_{100} treatment compared to S_{300} treatment (Table 1). These results are indicative of better nutrient pool (except DTPA-Cu) being maintained in the rhizosphere with fertigation treatments (maintaining the uniform soil moisture content near field capacity throughout crop growth) compared to soil fertilization (facilitating higher quantity of zinc subjected to chemical precipitation). The sulphate form of Zn also indirectly aided in temporary lowering of soil *p*H within nutrient absorbing area of rhizosphere to account for higher available N, P and K to eventually register consequent increase in concentration of these nutrients in leaves. Previous studies in different citrus cultivars like

Sathgudi orange (Devi *et al.* 1996, Lakashmi *et al.* 2019a) and acid lime (Patel and Patel 1985) showed significantly higher micronutrient doses on soils of varying textures and water-holding capacity and orchard age with varying tree canopy, represented predominantly by humid tropical/subtropical climate. In our study, clay soils of central India with higher nutrient and available water capacity (18–20%) ensured much higher utilization efficiency compared to soils with coarser texture of loam or sandy loam with much lower available water capacity (10–12%). This is the reason that nutrient response studies are mostly suggestive in nature than interpretative, conspicuously lack repetitiveness spatio-temporarily in application (Srivastava and Singh 2008). In our study, we collected soil samples from below the drippers as well as between drippers for soil fertility analysis, but it very likelihood that plant available nutrients could be quite varying when compared the results from below the drippers *vis-a-vis* between drippers (Srivastava and Singh 2003, 2004).We need such attempts to be addressed through onward studies with variety of citrus cultivars to perch citrus nutrition research on a scientific ground and a way forward towards precise soil fertility appraisal for citrus. This is one of the prime reasons; crop-based soil health card is still below par in application over different agro-pedological conditions with the same crop.

Response on fruit quality: The premier fruit quality parameter, TSS/acid was observed more favorable with fertigation treatments (Juice content 42.87–43.52%, TSS 8.7–9.4%, acidity 0.82–0.87% and TSS/acid ratio of 10.00–11.52%, than soil fertilization (Juice content 41.26–42.15%, TSS 8.4–8.7%, acidity 0.91–0.95% and TSS/acid ratio of 8.94–9.56), supporting the superiority fertigation over soil fertilization. The highest average fruit weight, TSS and juice percent were observed maximum with F_{200} treatment followed by F_{300} coupled with lowest acidity (Table 2). On the other hand the lowest fruit weight, TSS and juice percent were observed with treatments involving soil application of $ZnSO_4$. The similar response on fruit yield and quality parameters with integrated use of water and nutrient was earlier reported in Nagpur mandarin (Shirgure *et al.* 2016), Sathgudi orange (Lakashmi *et al.* 2019b) and acid lime (Shirgure *et al.* 2004). However, it remains to be investigated, how zinc nutrition maintains those fruit quality parameters playing decisive role in consumer acceptability, besides any possible contribution in extending shelf-life of fruits.

Plant growth and fruit yield attributes: Higher canopy volume is considered pre-requisite to accelerate in fruit yield, because of the higher fruit bearing area. A significant increment in plant canopy volume was observed with both, S_{100}-S_{300} as well as F_{100}-F_{300}, showing for superior response of fertigation based treatments. The canopy volume was recorded much higher with F_{200} (78.92 m^3) than F_{300} (78.24 m^3). However, the lowest plant canopy (75.42 m^3) was observed with S_{100} treatment due greater in immobilization of applied zinc in the soil. The fruit yield varied from 11.50 to 13.93 tonnes/ha with treatments, carrying S_{100} – S_{300} compared to 15.65 to 16.43 tonnes/ha with F100–F_{300} treatments. These observations suggested that Zn fertigation treatments out-smarted soil application of Zn, in accordance to change in leaf Zn concentration. The highest fruit yield was observed with treatment F_{200} followed by F_{300} and F_{100} in decreasing order (Table 2). The tree efficiency, a measure of fruit yield vis-a-vis canopy volume was observed significantly higher with fertigation treatments over soil application, indicating the response of Zn-induced increase in fruit yield at a much lower canopy volume . Such responses could also be explained interring of improved water translocation and resistance to water transport in xylem facilitated by improved availability of Zn, in addition to more developed xylem and phloem transport systems, resulting in reduced starch grains and polyphenol substances in leaf tissues (Srivastava and Singh 2004). The onward studies on scheduling entire fertigation, emphasizing types of nutrients required across crop phonological growth stages would impart a far greater acceptability to fertigation with value added responses. At the same time, a stronger need is felt to domesticate the conventionally used cheaper fertilizers in tailoring fertigation requirement of different commercial citrus cultivars (Shirgure 2012, 2013).

The tree efficiency was recorded significantly higher with F_{200} over S_{200} on an equipment basis. These findings were earlier reported through response of various irrigation

Table 1 Response of soil versus fertigation treatments of $ZnSO_4$ on the leaf nutrients composition and soil fertility changes in Nagpur mandarin (pooled data: 2013–17).

Treatment	Leaf nutrient concentration						
	Macronutrients (%)			Micronutrients (ppm)			
	N	P	K	Fe	Mn	Cu	Zn
S_{100}	2.18	0.08	1.31	78.4	72.3	10.1	22.3
S_{200}	2.22	0.10	1.42	80.1	69.4	10.1	24.1
S_{300}	2.31	0.10	1.51	79.6	71.1	11.2	25.7
F_{100}	2.30	0.11	1.61	78.4	71.2	11.8	25.1
F_{200}	2.44	0.14	1.98	79.2	71.8	11.9	27.8
F_{300}	2.40	0.12	1.82	80.1	72.1	10.9	26.8
CD (P=0.05)	0.09	0.05	0.33	0.34	0.25	NS	0.53
	Plant available nutrients (mg/kg)						
S_{100}	131.3	9.1	189.1	10.8	8.12	1.72	0.81
S_{200}	132.8	9.8	195.8	11.2	8.92	1.69	0.89
S_{300}	141.3	10.1	198.2	11.8	8.01	1.50	0.96
F_{100}	142.8	11.2	199.8	10.2	9.20	1.61	1.18
F_{200}	150.7	13.1	206.4	10.8	8.90	1.52	1.28
F_{300}	160.8	12.9	211.3	11.4	8.18	1.58	1.26
CD (P=0.05)	3.2	0.50	2.8	NS	NS	NS	0.04

N, P, K, Fe, Mn, Cu and Zn were extracted as $KMnO_4$-N, Olsen–P, NH_4OAc-K, DTPA-Fe, DTPA-Mn, DTPA-Mn and DTPA-Zn, respectively. Treatment details are given in Materials and Methods.

Table 2 Response of soil versus fertigation treatments of $ZnSO_4$ on tree efficiency, fruit yield and fruit quality attributes of Nagpur mandarin (pooled data: 2013–17)

Treatment	Plant growth and fruit yield				Fruit quality parameter				
	Canopy volume (m^3)	Fruit yield (kg/tree)	Yield (tonnes/ha)	Tree efficiency (kg fruits/m^3)	Fruit weight (g)	TSS (%)	Juice (%)	Acidity (%)	TSS/ acidity ratio
S_{100}	69.11	41.5	11.50	0.600	151.5	8.4	41.62	0.94	8.94
S_{200}	73.05	50.3	13.93	0.689	160.7	8.6	41.88	0.95	9.05
S_{300}	73.69	48.6	13.46	0.660	187.1	8.7	42.15	0.91	9.56
F_{100}	75.42	56.5	15.65	0.749	182.7	8.7	42.94	0.87	10.00
F_{200}	78.92	59.3	16.43	0.752	190.8	9.45	43.52	0.82	11.52
F_{300}	78.24	57.1	15.82	0.730	187.6	9.32	42.87	0.84	11.10
CD (P=0.05)	0.048	1.8	2.84		1.02	0.21	0.42	0. 07	0.38

Treatment details are given in Material and Methods.

studies on different citrus cultivars like Nagpur mandarin (Shirgure *et al.* 2014) and acid lime (Pawar *et al.* 2020), though under different agro-ecological regions. Quality fruits of Nagpur mandarin were observed far superior with zinc fertigation compared soil application of $ZnSO_4$. Our observations showed that zinc fertigation improved the internal fruit quality, besides accelerating an early fruit maturity and color break. All these plant responses were validated through an elevated leaf nutrient status *vis-a-vis* favourable soil fertility changes, ultimately saving nearly 33% of $ZnSO_4$ over soil application. Having worked out these issues, it is strongly advocated to develop a comprehensive guideline narrating the complete fruit quality appraisal details governing the market preference, not the conventionally analyzed internal fruit quality parameters alone.

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