



Effect of N and P fertigation on fruit yield and quality of kinnow

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Received: 29 March 2023; Accepted: 17 April 2023

ABSTRACT

The effects of N and P fertigation on productivity and quality of kinnow mandarin were investigated in south-western part of Punjab at the Regional Research Station, Abohar of Punjab Agricultural University, Ludhiana, Punjab during 2018–2020. Different combinations of the recommended dose (RD) of N and P, viz. 100, 75, and 50% were applied in equal splits at 5 stages of kinnow trees (February–October) and compared with conventional flood irrigation plus soil fertilization. The results showed that fertigation resulted in higher nutrient uptake, total leaf chlorophyll content, and vital physiological processes as compared to conventional practices. Tree volume under fertigation was about 29% higher than conventional practices. The data also revealed a significantly higher fruit set (20.13%), fruit weight (168.6 g), and fruit size (7.68 cm) as compared to flood irrigation plus soil fertilization. Fruit yield was about 33% higher in fertigated trees over flood irrigation and soil fertilization. Further, fruit quality parameters especially in terms of per cent juice, TSS-acid ratio, and ascorbic acid concentration were also superior in fertigated trees. In addition, fertigation resulted in a higher proportion of economic fruit grades over conventional flood irrigation and soil fertilization. The results suggest that fertigation @75% of N and P of recommended dose exhibited higher growth and productivity of kinnow mandarin, saving 25% N and P usage with better grade and higher quality of kinnow.

Keywords: Fertigation, Fruit grade, Nutrient use efficiency, Photosynthesis rate, Stomatal conductance, Yield

Citrus is an important fruit crop of tropical and subtropical climates. It is commercially cultivated in more than 53 countries on an area of 1393.9 thousand hectares (ha) with a production of 13898.4 thousand million tonnes (MT) (Anonymous 2018). In India, citrus fruits stand next to mango and banana and occupy about 10% of the total area among fruit crops. These are mainly grown on an area of 1.05 million ha with an estimated production of 14.03 million tonnes (Anonymous 2020). Kinnow is mainly grown in Punjab, Haryana, and the North-Western parts of Rajasthan. In Punjab, Kinnow occupies 53,045 ha area with an average annual production of 12.46 lakh tonnes. It is the principal citrus crop in the state and represents ~93% of the total area under citrus fruits (Anonymous 2019a). The area under kinnow cultivation is increasing rapidly in the state due to growing market demand and higher returns per unit area (Kumar *et al.* 2022).

Fertilization with flood irrigation using canal water is a common practice in citrus orchards in the south-western districts of Punjab. It has several drawbacks in

terms of losses of nutrients and irrigation water through conveyance, percolation, evaporation, and distribution (Shirgure 2012). In addition, for the past few years, meeting crop water requirements during the most critical fruit growth stages is a major problem due to frequent canal closures as a part of routine work by the irrigation department for the maintenance of canal networks throughout the state. Under such conditions, proper nutrient management in the orchards also gets obstructed. Fertigation technology in citrus has shown invariably a good response on growth, yield, quality, and uniform distribution pattern of applied water besides considerable savings in water and fertilizer usage (Shirgure 2012). However, no systematic study on the effect of N and P fertigation on the productivity of kinnow mandarin has been conducted especially in Punjab. Keeping this in view, investigations were conducted to see the effects of N and P fertigation on the growth, yield, and fruit quality of Kinnow mandarin.

MATERIALS AND METHODS

The present study was carried out at the Regional Research Station, Abohar of Punjab Agricultural University (PAU), Ludhiana (Punjab) during 2018–20 to study the effects of N and P fertigation on productivity and quality of kinnow mandarin. The experimental area was

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185.8 m amsl and lied between 30°9'0" N and 74°11'0" E. The climate of the study area was semi-arid type (agro-climatic zone-V). The experiment was laid out on 7-year-old kinnow plants budded on Jatti Khatti (*Citrus jambhiri* Lush) rootstock planted at a spacing of 5.4 m × 4.8 m. Treatment comprised of combinations of N and P as T₁, 100/100%; T₂, 100/75%; T₃, 75/75%; T₄, 75/50% and; T₅, 50/50% of the recommended dose of fertilizer (RDF), respectively along with T₆, standard check RD (880 g N + 440 g P₂ O₅/plant + 80 kg FYM/plant) and flood irrigation was applied at 15 days intervals during summer and at monthly interval during winter. Nitrogen was applied in two equal splits one in February and the second in April and phosphorus was applied along with first split of nitrogen in standard check. FYM was applied uniformly in the month of December in all the treatments. For fertigation, RDF was applied in 5 equal splits in different stages of kinnow trees. The stages include, the growth initiation period (mid-February to March), flowering and fruit set (March–April), initial fruit development (May–June), mid–fruit development (July–August) and pre-harvest fruit development (September–October). The fertigation was done at monthly intervals during the growth initiation period and pre-harvest fruit development stage and at fortnightly intervals during the rest of the growth period. Urea (46% N) and mono ammonium phosphate (MAP; 12:61:0) were used as sources of fertilizers and their calculated doses were applied at different stages.

The experiment was arranged in a randomized block design (RBD) with 3 replications per treatment. A replication comprised of a unit of three trees. Irrigation scheduling and other cultural practices were followed as per the standard package and practices for fruit crops, PAU Ludhiana (Anonymous 2019b). Leaf samples for nutrient analysis were collected from non-fruiting terminals in the month of September (Manivannan and Chadha 2011) and analyzed for N, P, and K content (Jackson 2005). Photosynthesis rate (Pn), stomatal conductance (Sc), and transpiration rate (Tr) were recorded by using a portable infrared gas analyzer (LI-COR-6400, Lincoln, Nebraska, USA) during different growth stages. The data were recorded at monthly intervals from March–October and represented stage-wise: stage-I, March–April; stage-II, May–June; stage-III, July–August; stage-IV, September–October. All measurements were made between 10:00 and 12:00 hours (Ribeiro *et al.* 2009). Total leaf chlorophyll estimation was done by standard method of Hiscox and Israelstam (1979). Leaf proline content was estimated as per the procedure given by Bates *et al.* (1973). The data were also recorded on tree height and spread in the first week of March. Tree canopy volume was calculated from tree height and average tree spread as per the formula $(4/3 \pi a^2b)$ given by Westwood (1993) where, $a = \frac{1}{2}$ the major axis (height) and, $b = \frac{1}{2}$ the minor axis (spread). The fruit set was estimated by counting the number of fruits after 20 days from full bloom out of the total number of flowers present on selected branches during bloom (in March) and expressed in percentage. Fruit drop (May–December) in each tree was counted periodically

Table 1 Effect of N and P fertigation treatments on soil, leaf nutrient status, growth and yield of kinnow mandarin

Treatment	Available nutrients in soil (kg/ha)			Leaf nutrients (%)			Tree growth parameters			Yield and yield attributes				
	N	P	K	N	P	K	Tree spread (m)	Tree height (m)	Canopy volume (m ³)	Fruit set (%)	Fruit no./ tree	Fruit wt. (g)	Fruit dia. (cm)	Sp. gravity
T ₁	185.8	20.7	432.1	2.84 ^a	0.166 ^a	1.12	3.71 ^a	3.12 ^a	22.61 ^a	20.13 ^a	558.0 ^a	168.6 ^a	7.68 ^a	0.97 ^a
T ₂	186.2	19.3	435.7	2.78 ^a	0.155 ^b	1.11	3.64 ^{ab}	3.08 ^{ab}	21.57 ^a	19.45 ^a	550.3 ^a	167.2 ^a	7.66 ^a	0.97 ^a
T ₃	183.6	20.7	436.6	2.72 ^{ab}	0.154 ^b	1.11	3.61 ^{ab}	3.05 ^b	20.97 ^a	19.12 ^a	545.5 ^a	165.7 ^a	7.63 ^a	0.97 ^a
T ₄	182.4	20.5	434.7	2.70 ^b	0.141 ^c	1.10	3.29 ^c	2.83 ^c	16.19 ^b	14.45 ^c	458.9 ^c	133.2 ^c	6.86 ^b	0.91 ^b
T ₅	174.8	20.7	420.6	1.96 ^d	0.139 ^c	1.09	3.16 ^c	2.62 ^d	13.77 ^c	12.15 ^d	424.6 ^d	125.8 ^d	6.75 ^c	0.87 ^c
T ₆	178.2	20.1	411.7	2.14 ^c	0.128 ^d	1.11	3.39 ^{bc}	2.88 ^c	17.45 ^b	17.67 ^b	487.9 ^b	144.2 ^b	6.26 ^d	0.93 ^b
CD (P=0.05)	NS	NS	NS	0.12	0.006	NS	0.27	0.06	1.69	1.24	18.3	3.14	0.10	0.02

*Average of 2018–19 and 2019–20. Treatments details are given under Materials and Methods.

and expressed as per cent drop out of total fruit retained. The data on the number of fruits on each tree, fruit weight, specific gravity, and fruit yield was recorded following standard procedures. Fruit peel thickness was measured with the help of Vernier callipers. Juice content in fruit is expressed as per cent of total fruit weight. Total soluble solids (TSS) in fruit juice were determined with the help of a hand refractometer. Titratable acid content, ascorbic acid content, and reduced sugar content of fruit were also determined following standard procedures of A.O.A.C. (2005). At the time of harvesting, fruits were also sorted and graded into 5 categories based on market acceptability, viz. A⁺ (>80 mm), A (70–80 mm), B (60–70 mm), C (50–60 mm), D (<50 mm fruit diameter). The proportion of fruit in each grade (by weight) was worked out and expressed in per cent. The data were analyzed using SAS package (9.3 SAS Institute Inc, USA). The least significant difference was used as a post hoc method to compare the difference in treatment means.

RESULTS AND DISCUSSION

Available N content in soil varied between 174.8–186.2 kg/ha among different treatments however, the differences were statistically non-significant (Table 1). Similarly, available P and K in soil did not vary significantly among treated treatments. Leaf nutrient was significantly influenced by different treatments. Treatment T₁ registered the highest N content (2.84%) which was statistically higher than conventional practice (T₆). Similarly, leaf P concentration was significantly higher in T₁ (0.16%) over T₆ (0.13%). These results suggest higher nutrient uptake under fertigation over conventional fertilization. These findings are in accordance with those of Naik *et al.* (2016) in banana cv. Grand Naine, and Kuchanwar *et al.* (2017) in Nagpur mandarins.

The differences in N and P leaf concentrations between fertigation and conventional fertilization may be ascribed to a continuous supply of nutrients in small amounts under fertigation. This might have well synchronized the plant's needs during different growth stages. On the other hand,

under conventional applications (T₆), a bulk volume of nitrogen and phosphorus fertilizers was applied along with surface irrigation. This might have resulted in greater nutrient losses, especially of N as reported by Quiñones *et al.* (2007). Besides, less nutrient uptake under T₆ may also be attributed to the wide fluctuation of soil moisture in the root zone during the growth periods. Furthermore, among different fertigation levels (T₁–T₅), values between T₁, T₂, and T₃ were statistically comparable for leaf N concentration. For leaf P, T₁ registered a significantly higher value over other fertigation levels (Table 1).

Fertigation (T₁) significantly improved the rate of vital physiological processes like photosynthesis rate and stomatal conductance over conventional fertilization (T₆) during different growth stages. The transpiration rate was significantly higher in fertigated trees (Fig 1), especially during stages III (Initial fruit development stage) and IV (mid-fruit development stage) over conventional fertilization. Higher vital physiological processes under fertigation over conventional soil fertilization may be due to higher water and nutrient uptake under T₁ owing to more congenial conditions in the root zone and better synchronization of crop needs for water and nutrients during different growth stages. The transpiration rate did not vary so much between stage III and stage IV which could be attributed to the tightly closed stomata in nitrogen-deficient plants as compared to plants that received optimum nitrogen under ambient soil moisture conditions. Reduced photosynthetic efficiency in citrus due to degradation of leaf chlorophyll content, reduced activity of enzymes, and reduced photochemical efficiency of Photosystem II (PS II) under water and nutrient stress was also reported by Nirgude *et al.* (2016) in Mosambi. Higher proline content in T₆ as compared to T₁ in the current study is also a testimony of the fact that trees with T₆ were under higher stress levels during different growth stages (Table 2). Among different fertigation levels (T₁–T₅), the highest photosynthesis rate during stage-I was noted in T₁ (4.56 µmol/m²/s) which was statistically at par with T₃ and T₂. Similar observations were made during stage II and stage IV. During stage III, the value was higher in T₁ and

Table 2 Effect of different treatments on total leaf chlorophyll and proline content*

Treatment	Total chlorophyll (mg/g)				Leaf proline content (µmoles/g)				Fruit drop (%)			
	Stage-I	Stage-II	Stage-III	Stage-IV	Stage-I	Stage-II	Stage-III	Stage-IV	Stage-I	Stage-II	Stage-III	Stage-IV
T ₁	1.87	1.9	1.88	1.85	4.98	5.62	5.53	5.41	12.30 ^c	3.00 ^c	5.03 ^{cd}	2.16 ^c
T ₂	1.86	1.88	1.85	1.83	5.09	5.94	5.66	5.61	11.86 ^c	3.17 ^c	4.98 ^d	2.78 ^d
T ₃	1.83	1.85	1.83	1.80	5.16	6.15	5.77	6.55	12.13 ^c	2.96 ^c	4.93 ^d	2.58 ^d
T ₄	1.81	1.83	1.82	1.79	5.38	6.07	5.93	6.15	13.60 ^b	3.59 ^a	5.43 ^b	3.22 ^c
T ₅	1.73	1.76	1.73	1.69	5.54	6.61	6.48	7.38	14.21 ^b	3.74 ^a	5.33 ^{bc}	3.60 ^b
T ₆	1.78	1.82	1.74	1.73	5.4	6.62	7.54	9.14	15.87 ^a	3.47 ^b	6.24 ^a	4.72 ^a
CD (P=0.05)	0.053	0.064	0.056	0.064	0.17	0.22	0.21	0.23	0.88	0.25	0.38	0.28

*The data is average of 2018–19 and 2019–20. Treatments details are given under Materials and Methods.

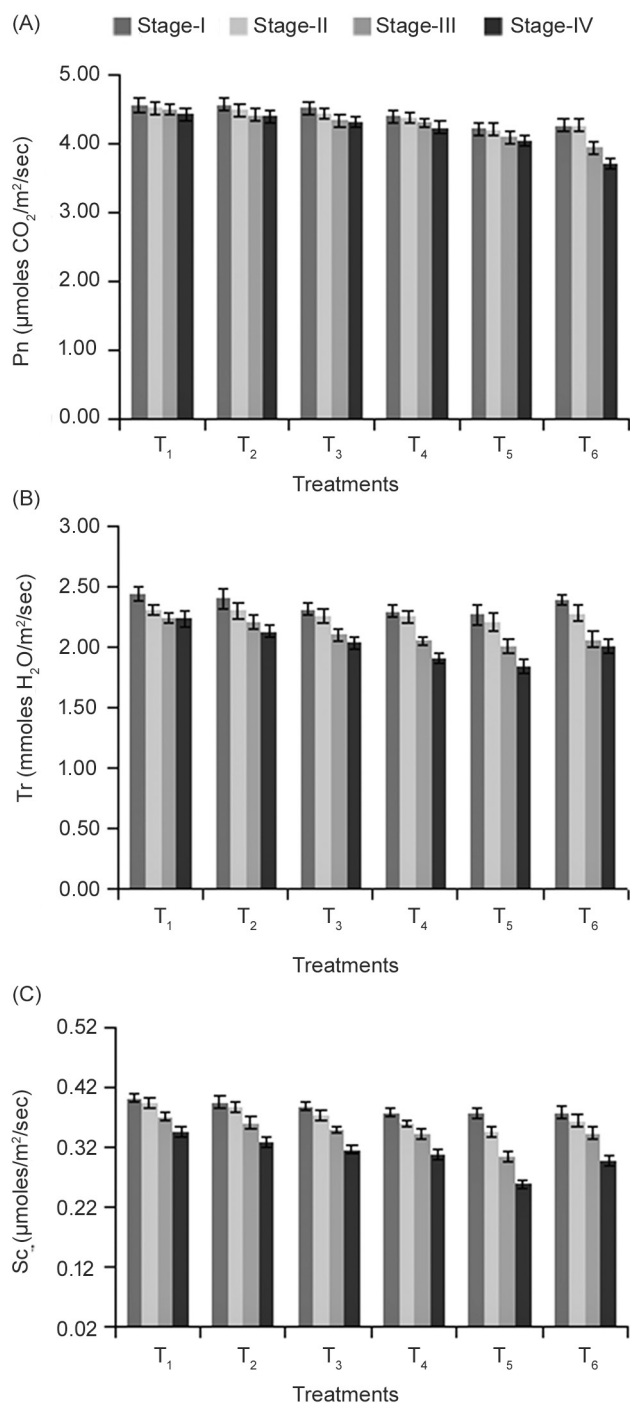


Fig 1 A, Influence of varying rates of N and P fertigation on Photosynthesis [P_n]; B, Transpiration rate [T_r] and; C, Stomatal conductance [Sc]. Means with vertical bars are significantly different (at $P \leq 0.05$). The vertical bar at each data point represents the standard error of means. Treatments details are given under Materials and Methods.

statistically comparable with T₂ (Fig 1). The data suggests a higher photosynthetic rate at higher application doses of fertilizers. Photosynthesis is the key factor affecting biomass accumulation and the economic yield of every fruit. The data elaborates a reducing trend in photosynthesis rate with

the advancement of the growth period in all treatments suggesting that the control plants remained under stress during the critical growth stage. Almost a similar trend was recorded, between stomatal conductance (Fig 1), and leaf chlorophyll content (Table 2) during different growth stages. Higher leaf chlorophyll content and the rate of vital physiological processes at higher fertigation levels have also been observed by Panigrahi and Srivastava (2017) in Nagpur mandarin.

Significantly higher tree height, average spread (EW and NS), and canopy volume were observed in fertigation (T₁) as compared to conventional practices (Table 1). This may be the result of higher vital physiological processes in fertigated trees. A similar observation was also made by Shirgure *et al.* (2016) in Nagpur Mandarin. Sinha *et al.* (2019) also reported maximum plant height, stem girth, and canopy volume with 120% RDF in kinnow. Likewise, fertigation also exhibited a significantly higher fruit set T₁ (20.13%) over T₆ (17.67%). Quite heavier fruits (fruit weight and specific gravity) were also observed in fertigated trees. In addition, fertigation also retained a significantly higher number of fruit per tree up to maturity (~14%) as compared to conventional irrigation and fertilization practice. Fruit yield was about 33% higher under fertigation over conventional practices of irrigation and fertilization. Higher tree vigour might have resulted in higher production of photosynthates. This might have caused increased fruit size and weight, less fruit drop, and finally higher yield under fertigation. The importance of tree vigour in light interception and its importance in the synthesis of photosynthates have well been documented by Duncan (1971). Further, among different fertigation levels (T₁–T₅), tree vigour, yield, and yield attributing parameters were statistically comparable among T₁ (100% RD of N and 100% RD of P), T₂ (100% RD of N and 75% RD of P) and T₃ (75% RD of N and 75% RD of P).

Fertigation (T₁) registered significantly higher A⁺ and A grade fruits over conventional flood irrigation and fertilization practices (T₆). These results suggest that fertigation resulted in a higher number of fruits which is economically more important and acceptable. Among different fertigation levels, A⁺ and A grade fruits were statistically comparable in T₁, T₂, and T₃ whereas, comparatively smaller fruits (grade B, C, and D) were higher in T₄, T₅, and T₆ treatments.

Except for peel thickness and titratable acidity, fruit quality parameters were significantly influenced by fertigation (T₁) over conventional irrigation and fertilization (Table 3). Higher juice content under fertigation may be the result of optimum soil moisture content and better synchronization of nutrient demand and supply relationship (Grace 2011). Higher TSS and reducing sugars may be due to higher production of photosynthates as a result of hydrolysis of starch (Table 3). Higher fruit quality index (TSS-acid ratio) in fertigated trees may therefore be ascribed to higher TSS and low acid concentration in fruit juice (Table 3). The higher ascorbic acid concentration was also observed in fertigated trees. Furthermore, a comparison

Table 3 Effect of different treatments on fruit drop and quality parameters of kinnow*

Treatment	Peel thickness (cm)	Juice (%)	TSS (%)	Acidity (%)	TSS/acid ratio	Reducing sugar (%)	Ascorbic acid (mg/100 ml)	Nitrogen use efficiency (kg/kg)	Phosphorus use efficiency (kg/kg)
T ₁	5.03 ^a	50.73 ^a	11.54 ^a	0.86	13.42 ^a	3.57 ^a	25.32 ^a	106.1	212.3
T ₂	4.97 ^a	50.57 ^a	11.50 ^a	0.85	13.52 ^a	3.53 ^a	25.21 ^a	103.8	278.3
T ₃	4.86 ^b	50.60 ^a	11.51 ^a	0.85	13.54 ^a	3.48 ^a	25.05 ^a	135.8	273.1
T ₄	4.85 ^b	47.23 ^b	11.15 ^b	0.87	12.81 ^{ab}	3.25 ^b	24.26 ^b	92.1	276.2
T ₅	4.81 ^b	45.68 ^b	10.86 ^c	0.89	12.19 ^b	3.12 ^b	24.15 ^b	120.7	241.5
T ₆	5.06 ^a	46.70 ^b	10.93 ^{bc}	0.89	12.08 ^b	3.24 ^b	24.09 ^b	79.4	158.8
CD (P=0.05)	0.09	1.97	0.25	NS	1.02	0.13	0.67	-	-

*Average of 2018–19 and 2019–20. Treatments details are given under Materials and Methods.

among different fertigation levels revealed higher per cent juice, TSS, reducing sugar content, and ascorbic acid concentration in T₁ but was statistically at par with T₂ and T₃. Higher quality parameters in sweet oranges at higher fertigation levels were also reported by Hendre *et al.* (2020). Data showed that values of nutrient use efficiency were higher in fertigation treatments as compared to control during the present investigation. The maximum value of nitrogen use efficiency (135.8 kg/kg) was noted in T₃ while the minimum value (79.4 kg/kg) was recorded in the control (T₆). In addition to this, the phosphorous use efficiency was maximum (278.3 kg/kg) in T₂ followed by T₄ and T₃ (273.1 kg/kg) whereas, treatment T₆ registered the minimum value of phosphorous use efficiency (158.8 kg/kg) that was lower than all the treatments (Table 3). The result of the linear regression between the selected parameters shows, positive relationship between leaf-N and yield ($R^2 = 0.573$), leaf-P and yield ($R^2 = 0.622$), juice percentage and yield ($R^2 = 0.938$), and TSS/acid ratio and yield ($R^2 = 0.7304$) suggesting that the fertigation has resulted in better nutrient uptake, yield and other fruit quality parameters.

In the present investigation, it comes out that fertigation proved its superiority over conventional flood irrigation plus soil fertilization due to frequent water and nutrient supply directly in the root zone during different growth stages. Fertigation resulted in higher water and nutrient uptake, vital physiological processes, tree vigour, and consequently higher yield. Fruit quality parameters especially juice content; TSS-acid ratio and ascorbic acid concentration were also superior under fertigated trees. Further, in general, treatment comprised of 100% recommended dose (RD) of N and 100% RD of P and 75% RD of N and 75% RD of P were statistically comparable. Hence, it is concluded that fertigation in sandy loam soils resulted in 25% savings in N and P fertilizers over conventional flood irrigation plus soil fertilization practices besides higher yield and quality of fruits.

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