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Nitrogen fertigation for nectarines (*Prunus persica* var *nucipersica*): Lateral and vertical nutrient acquisition and cropping behavior in rainfed agroecosystem

DEEPIKA SINGH[1], SOM DEV SHARMA[2] and PRAMOD KUMAR[3]

Dr Y S Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh 173 230

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ABSTRACT

The present investigation was planned and focused with the objective to compare the effect of nitrogen (N) fertigation and conventional soil fertilization on growth and nutrient dynamics for the establishment of Snow Queen nectarines (*Prunus persica* var. *nucipersica*). We determined if the frequency of application of fertigation that could modify cropping behavior of the plantations in integrated horticultural based cropping system under rainfed ecosystem. In the experiment, all plants received the same amount of water with sufficient fertilizer N but the treatment included four fertigation frequencies applied weekly intervals of the recommended dose (RD) of N fertilizers over conventional soil fertilization scheduled at 25% (25% RD-N fertigation), 50% (50% RD-N fertigation), 75% (75% RD-N fertigation) and 100% (100% RD-N fertigation) in the Randomized Block Design replicated thrice. The availability of nutrients at root zone of the trees significantly influenced vegetative growth attributes, the uptake of macro- and micronutrient cations and fruit quality characteristics. Given the fact that all treatments applied with adequate and equal amount of fertilizer and water, however, 75% RD-N fertigation frequency had significantly affected cropping behavior and uptake efficiency both vertically as well as horizontally. The N availability steadily increased with increased depth up to 30 cm after that declined in all the distances at fertigation with 75% RD-N. Highest available P and K in soil was confined to 0-15 cm of soil layer under all fertigation levels and decreased with increase in distance from the emitters and soil depth. With regards to exchangeable Ca and Mg, the contents were decreased in the surface soil than in the subsoil. This superior application also recorded improved vertical and horizontal distribution of available macro- and micronutrient cations in soil, leaf nutrient concentration and fruit quality attributes for growth parameters and fruit quality characteristics which in turn saved 25% of the inorganic fertilizers application.

Key words: Drip irrigation, Growth performance, Mineral nutrients, Soil depth

Drip irrigation technique have facilitated the adoption of the application of the fertilizers to crops through irrigation water which saved 29–78% in the application cost resulted due to the improved efficiency of water soluble fertilizer application, low fertilizer leaching, the precise nutrient application and right-amount at a right-time fertilizers' application. To optimize nutrient management with drip irrigation would require attention to soil nutrient dynamics, crop nutrient requirements, as well as soil and plant monitoring techniques. Nitrogen (N) is the most commonly applied nutrient element through drip irrigation, often injected as urea and ammonium salt which has improved the yield and quality of fruits (Haynes 1985). In general, nitrogenous fertilizers are suitable for drip fertigation, caused little clogging and precipitation except ammonium sulphate. On the contrary, urea is well suited for the injection through fertigation due to highly soluble nature, dissolves in non-ionic form and also does not react with substances in the water. Moreover, nitrate salts are characteristically soluble and are well suited for fertigation. Earlier scientific reports revealed that the application of N fertilizers through fertigation improved growth, yield and quality of apple (Buban and Lakatos 2000, Singh *et al.* 2007), citrus (Melgar *et al.* 2010), cherry (Ahmad *et al.* 2010), pomegranate (Rao and Subramanyam 2009) and banana (Kumar and Pandey 2008). Fertilizers applied through broadcasting under basin method of irrigation are not efficiently utilized by the plants. Fertigation also ensures application of fertilizers directly into the site of active root zone. It also offers the vast potential for more accuracy and timely crop nutrition besides considerable saving in fertilizers (Raina 2002, Raina *et al.* 2005). In India, the nutrient and water use efficiency of the

[1]Ph D Scholar (e mail:deepisinghnov22@gmail.com), Department of Fruit Science, Dr YS Parmar UHF, Nauni, Solan, HP 173 230; [2]Principal Scientist (Fruit Science), (e mail: somdevsharma2001@rediffmail.com), Department of Horticulture, COHF, Dr Y S Parmar UHF, Neri, Hamirpur, HP; [3]Scientist (Fruit Science), (e mail: pk43sharma@yahoo.co.in), RHRTS-Dr Y S Parmar UHF, Dhaulakuan, Sirmour, HP 173 031

key inputs is currently very low resulting in low crop productivity, continual degradation of soil health and the increased environmental pollution apart from the wastage of substantial quantity of these costly and scarce inputs. Moreover, the increased efficiency can itself go a long way that realizes the growing demand for food and other plant products consequent to rapidly escalating population. In fertigation, nutrient use efficiency recorded as high as 90% compared to 40-60% in conventional soil fertilization. The amount of fertilizer lost through leaching could be as low as 10% in fertigation, whereas, it is 50% in the traditional system (Solaimalai *et al.* 2005).

Nectarines (*Prunus persica* var. *nucipersica*) are one of the prime stone fruits of warm temperate climate and its cultivation to a lesser extent is spread in the subtropics of the world. It requires relatively warmer climate than other temperate fruits. Commercially, nectarines are fuzzy and smooth skinned, characterized by the absence of fruit skin trichomes, little smaller in size, firm fleshed and may possess stronger flavor and aroma produced due to a recessive allele for fuzzy skin. Among commercial cultivation, the cultivar Snow Queen considered the most important, is an outstanding low chill variety with 250-300 chilling hours, light skin blushed with russet, flesh is white, freestone, juicy, self fertile and early maturing variety. Its cultivation extends from northern plains (2000 m above mean sea level) with an annual production of 114000 MT (NHB 2000). In Himachal Pradesh, both nectarines and peaches are commercially cultivated in the area of 4 800 ha, which is scattered all over the state except the dry and cold regions of Lahaul and Spiti, Kinnaur, Pangi and Bharmour areas of Chamba district, with an annual production of about 6 564 MT (Anonymous 2007). During an orchard establishment, the young trees should be fertilized to obtain desired vegetative growth to develop tree framework within 4-5 years while striving to minimize over fertilization especially with N. Keeping in view, the present investigations were planned and focused with the objective to study the comparable effect of different N fertigation levels vis-à-vis traditional soil fertilization on cropping behavior and nutrient acquisition of nectarines in integrated horticultural based farm sequencing system under rainfed agroecosystem.

MATERIALS AND METHODS

The present investigation was carried out on two year old nectarine trees of cultivar Snow Queen in the 'Integrated Horticulture Farming System Model Farm' of Dr Y S Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh, India between 2012 and 2013. The trees were planted at distance of 4m × 2 m apart. The experimental orchard is located at an altitudinal gradient of 1256 m above mean sea level, lies between the coordinates of 30°50'30" north latitude and 77°88'30" east longitude, represented the mid hill zone of the State. The climate of the area is typically sub-temperate. The annual rainfall ranged between 800 and 1300 mm. The experimental soil was texturally classified as sandy loam following physical and chemical characteristics: sand: 40.2%; silt: 30.4%; clay: 29.7%; pH (H_2O) 7.06; electrical conductivity (EC) 0.56 dS/m and soil organic carbon (SOC) 0.53%. The chemical properties of the site at different soil depths of the model farm prior to the initiation of the experiment are depicted in Table 1.

Four levels of N fertigation scheduled at T_1-drip fertigation of 25% of the recommended dose of N (25% RD-N); T_2-drip fertigation of 50% of the recommended dose of N (50% RD-N); T_3-drip fertigation of 75% of the recommended dose of N (75% RD-N); T_4-drip fertigation of 100% of the recommended dose of N (100% RD-N); T_5-conventional soil fertilization with 100% of the recommended dose of fertilizers (RDF) as control (T_5) were evaluated. All the treatments were replicated thrice in randomized block design. RDF was applied as N: P: K (i) two year old (140: 70: 200 g/tree), (ii) one year old (70: 35: 100 g/tree) as basal application. Drip fertigation system contained four emitters with a discharge rate of 8 l/hr of the fertilizer solution at the basin of each tree and were placed in cross manner at an angle of 90Ú to each other and at a distance of 30 cm from the tree trunk. Fertigation was carried out through venturi, which works on the principle of a differential pressure that forms a vacuum. As water flows through the tapered venturi orifice, a rapid change in velocity occurs that creates a reduced pressure (vacuum), which has drawn the fertilizer solution injected into the system.

Fertigation with water soluble NPK fertilizers, viz. 46:00:00, 00:45:45 and 00:00:50 was accomplished at weekly intervals in twelve equal splits, starting from 14 March of the experimental year and continued till the end of May. To complete the N requirement under different treatments, urea was applied at weekly intervals. In different treatments with respect to P and K requirement of the plant were not implicated, only split doses were provided with PK (00:45:45). The split dose of water soluble K fertilizer (00:00:50) were used along with PK (00:45:45) to supplement the left out K_2O. At first, the fertigation was done with 25% recommended dose of fertilizers to all the trees. Afterwards, the supply to the plants under treatment T_1 was stopped with the help of closing and/or opening knobs. The recommended dose of 25% was applied to the

Table 1 Soil chemical properties measured at different depths of Snow Queen nectarines prior to the initiation of the experiment

Soil depth (cm)	pH	EC (dS/m)	SOC (%)	Macronutrients (mg/kg)			Exchange-able Ca	Exchange-able Mg	Micronutrients (mg/kg)			
				N	P	K	(mg/kg)	(mg/kg)	Fe	Cu	Zn	Mn
0-15	7.16	0.14	0.58	123.86	16.00	130.92	25.80	23.00	52.80	1.75	1.58	42.30
15-30	6.96	0.15	0.48	115.37	14.43	129.39	25.69	22.75	52.55	1.70	1.47	42.10

remaining plants (T_2). Similar procedure was adapted in T_3 and T_4, respectively. After each fertigation, drip system was thoroughly flushed for 15 minutes. Different doses of fertilizers were applied by regulating the supply with the help of closing and opening knobs. In conventional soil fertilization (T_5), N fertilizer was applied in two equal splits, i.e. the first half in the month of January, and the remaining half after one month of the first application. Full P and K fertilizers were applied in the first week of January during the experimentation.

A representative sample size of uniform and healthy shoots from the current season's growth in all the four direction of the tree were selected randomly for measuring annual shoot extension growth at monthly intervals. The net increase in the shoot length was recorded and was expressed in centimeter (cm). Before the execution of experiment, the tree trunk was labeled and subsequently the circumference of tree trunk was measured at 15 cm above the graft union using measuring tape and was expressed in centimeter (cm). Tree canopy volume was determined by calculating total above ground volume of each tree from height and spread method suggested by Westwood (1993) using formulae (i) for the trees taller than its width ($4/3\ \pi\ ab^2$) and (ii) for the trees wider than its height ($4/3\ \pi\ a^2b$), where a=½ of length of major axis and b=½ of length of minor axis. Canopy volume was calculated using the formula 'πr^2' in which radius mean was measured from all the directions of crown. For leaf area estimation, the representative sample size of 50 fully expanded and matured leaves were taken for the observations. Subsequently, the cumulative area was recorded with Leaf area meter model LI-COR-3100 and was expressed in square centimeter (cm^2). Similarly, for the estimation of the chlorophyll content of the leaves, the representative sample size of ten leaves from each treatment was collected during the month of July in the morning hours (Halfacre *et al.* 1968). The samples were then stored in refrigerator at sub-zero temperature to avoid the dehydration of the pigments. The 100 mg of chopped leaf samples were placed in vials containing 7 ml of dimethyl sulphoxide (DMSO). The extraction, estimation and bioassay of total chlorophyll content in leaf were done using Spectronic-20 at 645 and 663 nanometer (nm) wavelengths. The optical density (OD) value of the extract was recorded in spectrophotometer (Spectronic-20) at 645 and 663 nm wavelength against a DMSO as blank. Total leaf chlorophylls were calculated using the following formula as:

$$\text{Total chlorophylls} = \frac{20.2\ A_{645} + 8.02\ A_{663}}{a \times 1000 \times W} \times V$$

where, V, volume of the extract made; a, length of the light path in cell (usually 1 cm); W, weight of the sample; A_{645}, absorbance at 645 nm; A_{663}, absorbance at 663 nm. The results thus obtained were expressed as mg of total chlorophyll per gram of the fresh weight.

The harvested fruits were also utilized for the analyses of physical–chemical characteristics. Fruit firmness was determined using an Effigy Penetrometer model FT (Effigy, Pensylvania); total soluble solids (TSS), the acidity and total sugars were estimated using standard procedures (AOAC 1980).

Soil depth-wise distribution of available macronutrients (N, P, K), exchangeable cations (Ca, Mg) and micronutrients (Fe, Cu, Zn, Mn) in soil were determined. Composite soil samples both vertically and horizontally weighed up to 1 kg were collected below the emitters in each fertigation treatment. In each fertigation treatment, the samples were drawn at soil depth of 15 and 30 cm, and also at a distance of 15 and 30 cm away from the emitters, whereas, in conventional soil fertilization, the sampling was done at a distance of 45 and 60 cm away from tree trunk. The soil samples were then air dried, sieved (2 mm size), and were analyzed for various chemical characteristics using standard methods. Soil pH was measured in a 1:2 (w/v) soil: water suspension solution (Jackson 2005). SOC was determined according to wet oxidation method (Walkley and Black 1934). Available N was estimated using alkaline potassium permanganate method (Subbiah and Asija 1956), available P was determined according to Olsen's method (Olsen *et al.* 1954) and available K was extracted in 1N neutral normal ammonium acetate using a flame photometer (Merwin and Peach 1951). Exchangeable Ca and Mg were extracted with the neutral normal ammonium acetate. DTPA-extractable micronutrient cations (Fe, Cu, Zn, Mn), buffered at pH 7.3±0.05 (Lindsay and Norvell 1978), and then analyzed on Pye-Unicam SP-2000 double beam atomic absorption spectrophotometer. Simultaneously, a representative sample size of 50 fully mature and expanded leaves from the base of the current season's growth were also collected during July (Chapman 1964). The pre-treatments of the leaf samples involve drying, grinding and washing of the samples for further chemical analysis was carried out using standard methods. The digestion of leaf sample (1 g) for the estimation of total N was carried out in concentrated H_2SO_4, contained a digestion mixture of potassium sulphate (400 parts), copper sulphate (20 parts), mercuric oxide (3 parts) and selenium powder (1 part). For the estimation of P, K, Ca, Mg and micronutrients (Fe, Cu, Zn, Mn), the samples (0.5 g) in diacid mixture (HNO_4: $HClO_4$) in the ratio of 4:1 were digested. Total leaf N was determined using a nitrogen autoanalyzer, Kjeltech Foss Tecator model 2300, and P by the phosphovanadomolybdate method (Jackson 1973). K, Ca and Mg content were estimated on flame photometer.

Statistical analysis of the data was carried out using analysis of variance (ANOVA) to compare the efficacy of different N fertigation levels applied over conventional soil fertilization according to Panse and Sukhatme (1985). Significance of variation among the treatments was observed by employing Least Square Differences (LSD) at 5% level of probability.

RESULTS AND DISCUSSION

Vegetative growth attributes and total leaf chlorophylls

The growth of trees was evaluated by measuring the plant height, trunk girth, tree spread, annual shoot extension growth, leaf area of the trees. The measurements of the trunk cross-section area at the height of 30 cm above the soil were also recorded. The results inferred that plant height significantly influenced among different N fertigation treatments applied. The treatment T_4 (100% RD-N) recorded the maximum (3.63 m) plant height followed by T_3 (75% RD-N), T_2 (25% RD-N) with corresponding values of 3.54 and 3.47 m, respectively, but were significantly higher than conventional soil fertilization (T_5) and was statistical similar to T_1 (25% RD-N). However, 9.01% increase in plant height was observed in T_4 over T_5 (Table 2). Trunk girth did not show any significant variation with respect to N fertigation and conventional soil fertilization treatments. However, the percent increment in the trunk girth over control was proportionately related to N fertigation levels. Similarly, maximum tree spread (2.53 m) was recorded in T_4 which was statistically at par with T_3 (2.50 m) and T_2 (2.47 m), whereas, minimum of 2.34 m was recorded in T_1. In canopy volume (20.06%) and leaf area (17.52%), the maximum increase was recorded with treatments T_9 over T_5. Maximum annual shoot extension growth (1.61 m) was recorded in T_4 which was statistically at par with T_3 (1.58 m) and T_2 (1.52 m), whereas, minimum of 1.34 m was recorded in T_1. However, 17.52 per cent increase in the annual shoot extension growth of the trees was recorded in T_4 over control. Total leaf chlorophylls were also significantly influenced with T_4 (2.71 mg/g of total chlorophyll of fresh weight) followed by T_3, T_2 and T_1 with corresponding values of 2.69, 2.54 and 2.51 mg/g of total chlorophyll of fresh weight and an increase of 7.11 per cent was recorded in T_4 over conventional soil fertilization. The results showed that all the vegetative growth parameters and biochemical attributes were recorded in T_4 improved significantly which might be due the availability of the macro- and micronutrient content in the soil and water that are the key inputs for plant growth and developmental processes. The frequent application of water and nutrients might have met the plant requirements during the critical growth periods which in turn ascribed to increase the nutrient use efficiency by minimizing leaching losses. These favorable effects of fertigation in terms of higher growth parameters compared to conventional soil fertilization have also been reported by Treder (2006). They further concluded that trickle irrigation increased the nutrient use efficiency whether the fertilizers are soil applied or dissolved in irrigation water compared to conventional soil fertilization. In the present studies, the fertigation has lesser nutrient removal compared to conventional soil fertilization. Battillani (1997) observed higher tree growth and weight of pruned branches under fertigation compared to conventional soil fertilization. Furthermore, N fertigation have increased its uptake simultaneously with the increase in P and K uptake due to its synergistic effect which is also evident from the higher P and K content in the foliage under T_3 and T_4 as compared to T_1, T_2 and T_5. The increased nutrient uptake might have increased the rate of various physiological and metabolic processes in the plant system, thereby led to higher vegetative growth. Besides, the total chlorophylls of the leaves were influenced by different levels of N fertigation treatment. Hlusek *et al.* (1993) recorded an increased the chlorophyll content in leaves with the treatment application of urea than the other nitrogenous fertilizers. The studies were also further reported that urea significantly increased the chlorophyll b and chlorophyll a+b content by 81 per cent in apple.

Fruit quality characteristics

Fruit quality attributes also influenced by N drip fertigation and were assessed in terms of fruit dimension (length, breadth), fruit weight, TSS, acidity and total sugars content. The perusal of the data presented in Table 3 depicted that N fertigation had marked influence on fruit quality characteristics. Maximum fruit length (47.12 mm) was recorded in T_3 which was statistically higher than all other treatments applied. Similarly, the trees fertigated with 75% RD-N produced fruits with maximum breadth and weight (41.20 mm, 88.47 g) which was significantly higher than T_4, T_2 and T_1. Minimum acidity (0.53%) of fruits was recorded in T_1. It has also been observed that maximum reduction (3.64%) of the acid content was observed in T_1 over conventional soil fertilization. Maximum TSS (14.7 °Brix, B) was recorded T_3 and was statistically similar to T_4 noticed 14.5 °B, whereas, minimum (12.4 °B) TSS was observed in T_1. Highest total sugars (11.3%) were recorded in T_3 followed by 10.9 per cent in T_4, whereas minimum (8.91%) total sugars were recorded in T_1. Maximum increase of 20.47% in total sugars was noticed in T_3 over conventional soil fertilization. The improvement in fruit quality

Table 2 Nitrogen fertigation affects vegetative growth attributes and leaf chlorophylls content of Snow Queen nectarines

Treatment	Plant height (m)	Trunk girth (cm)	Tree spread (cm)	Canopy volume (m^3)	Annual shoot extension(m)	Leaf area (cm^2)	Leaf chlorophylls (mg/g)
T_1	3.28 (1.50)	29.08 (0.34)	2.34 (3.31)	9.38 (8.22)	1.34 (2.19)	38.8 (4.67)	2.51(0.79)
T_2	3.47 (4.20)	29.44 (0.89)	2.47 (2.07)	11.18 (9.39)	1.52 (10.95)	44.7 (9.83)	2.54(0.40)
T_3	3.54 (6.31)	29.84 (2.26)	2.50 (3.31)	11.56 (13.11)	1.58 (15.33)	48.6 (19.41)	2.69(6.32)
T_4	3.63 (9.01)	30.04 (2.95)	2.53 (4.56)	12.27 (20.06)	1.61 (17.52)	48.8 (19.90)	2.71(7.11)
Control	3.33	29.18	2.42	10.22	1.37	40.7	2.53
LSD (P=0.05)	0.24	NS	0.06	0.75	0.16	0.57	0.04

Figures in parentheses are per cent increase or decrease over control; NS, differences are not significant

Table 3 Effect of nitrogen fertigation on fruit quality characteristics of Snow Queen nectarines

Treatment	Fruit length(mm)	Fruit breadth (mm)	Fruit weight (g)	Titratable acidity (%)	TSS (^{0}B)	Total sugars (%)
T_1	32.65(9.68)	29.46(7.21)	64.62(4.01)	0.53(3.64)	12.4(0.8)	8.91(5.01)
T_2	40.73(12.67)	34.85(9.76)	72.36(7.49)	0.59(7.27)	13.5(8.0)	10.73(14.39)
T_3	47.12(30.35)	41.20(29.76)	88.47(31.42)	0.61(10.91)	14.7(17.6)	11.30(20.47)
T_4	44.35(22.68)	40.15(26.46)	86.18(28.02)	0.71(29.09)	14.5(16.0)	10.93(16.52)
Control	36.15	31.75	67.32	0.55	12.5	9.38
LSD (P=0.05)	0.06	0.01	0.35	0.04	0.15	1.21

TSS: Total soluble solids; ^{0}B: ^{0}Brix; Figures in parentheses are per cent increase or decrease over control

characteristics ascribed to the improved chemical properties of the soil, including decrease of soil pH towards neutral. Under fertigation, the uniform distribution of N coupled with its confinement in the root zone has increased the uptake that might be responsible for synthesis of more metabolites, their translocation and in turn increased size, weight and volume of fruits. Reddy *et al.* (2002) recorded significantly higher yield, fruit size, weight, and fertilizer use efficiency with fertigation compared to soil application in banana. In the present study, the treatments T_3 and T_4 significantly increased size, weight and volume of the nectarines fruits over T_1, T_2 and T_5 due to the increased synthesis of metabolites at higher N levels and further its translocation to the fruits. It is also apparent that N fertigation exhibited significant effect on acidity of fruits in T_4. A critical appraisal of the data further revealed that TSS increased with the significant differences in the total sugar content with increased N fertigation. These results get further support from the findings of Jia *et al.* (1999), where they documented that TSS content was highest in the medium dose and lowest in the high dose at harvest. These results also suggested that the excessive fertilizer application significantly diminishes fruit flavor by reducing sweetness and aroma in nectarines.

Soil chemical indicators

The data presented in Table 4 revealed that drip fertigation with N fertilizers changed soil pH towards neutral. Haynes *et al.* (1987) who reported a decrease in soil pH with the application of N fertigation as urea than broadcast application. On the contrary, a progressive increase in soil acidity noticed with the increase in N application rate in peaches (Patten *et al.* 1989). Similarly, maximum SOC (0.53%) was recorded at 0-15 and 15-30 cm soil depth in T_4 followed T_3, whereas, the least SOC (0.45%) was exhibited in T_2. The data also revealed that there were an increase of 5.77, 9.62, 13.46% and decrease of 5.77% in T_2, T_3, T_4 and T_1 at 0-15 cm soil depth, respectively compared to traditional

Table 4 Soil depth affects the vertical and lateral distribution of chemical characteristics of soil of Snow Queen nectarines

Treatment	Depth (cm)	pH	SOC (%)	N (mg/kg) Distance from emitting point (cm)			P (mg/kg) Distance from emitting point (cm)			K (mg/kg) Distance from emitting point (cm)		
				0	15	30	0	15	30	0	15	30
T_1	0-15	7.18	0.49	123.64	120.93	114.98	15.96	12.69	9.29	130.87	121.17	114.98
		(0.42)	(5.77)	(0.45)	(2.52)	(7.27)	(3.39)	(16.90)	(42.19)	(0.13)	(6.11)	(11.55)
	15-30	7.15	0.40	115.78	110.94	104.32	7.78	7.30	5.88	120.74	111.88	105.58
		(1.27)	(2.44)	(1.93)	(5.22)	(10.29)	(12.19)	(3.44)	(32.41)	(0.52)	(6.01)	(11.28)
T_2	0-15	7.15	0.55	133.51	130.10	124.00	22.52	19.62	16.42	146.03	136.33	130.14
		(0.00)	(5.77)	(7.49)	(4.87)	(0.00)	(36.32)	(28.49)	(2.18)	(11.44)	(5.63)	(0.11)
	15-30	7.05	0.44	122.13	118.30	116.79	10.42	10.22	9.42	136.53	127.13	119.83
		(0.14)	(7.32)	(3.45)	(1.07)	(0.44)	(17.61)	(35.19)	(8.28)	(12.49)	(6.81)	(0.70)
T_3	0-15	7.07	0.57	136.00	133.40	126.46	23.82	20.82	16.62	148.03	138.53	130.93
		(1.12)	(9.62)	(9.50)	(7.53)	(1.98)	(44.19)	(36.35)	(3.42)	(12.97)	(7.34)	(0.72)
	15-30	6.99	0.48	123.39	120.33	117.36	10.52	11.42	9.62	137.83	128.23	121.03
		(0.99)	(17.07)	(4.51)	(2.80)	(0.93)	(18.74)	(51.06)	(10.57)	(13.56)	(7.73)	(1.71)
T_4	0-15	6.97	0.59	142.50	136.70	130.60	23.92	21.12	16.72	150.10	140.40	133.00
		(2.52)	(13.46)	(14.73)	(10.19)	(5.32)	(44.79)	(38.31)	(4.04)	(14.55)	(8.79)	(2.31)
	15-30	6.88	0.48	126.70	123.40	118.44	10.62	11.72	9.92	140.30	130.80	123.20
		(2.55)	(17.07)	(7.32)	(5.43)	(1.86)	(19.86)	(55.03)	(14.02)	(15.60)	(9.89)	(3.53)
Control	0-15	7.15	0.52	124.20	124.06	124.00	16.52	15.27	16.07	131.04	129.06	130.00
	15-30	7.06	0.41	118.06	117.05	116.28	8.86	7.56	8.70	121.37	119.03	119.00

Figures in parentheses are per cent increase or decrease over control soil fertilization. Similar trend was also observed under 15-30 cm soil depth. This increase ascribed to the improved microbial activity which resulted in rapid decomposition of organic substances, thereby increased organic carbon of the soil. Further, an increased biomass added to the soil, with increasing N levels, which on degradation has led to the increase in the organic matter content of soil (Sharma 1994).

Lateral and vertical nutrient distribution

Drip fertigation with N fertilizers increased available N to variable extent. Depth-wise distribution indicated its decrease in the soil profile (up to 30 cm). Conventional soil fertilization also increased the available N; however, the magnitude varied markedly at different soil depths. The emitters at 0-15 cm soil depth increased N content in T_2, T_3, T_4 with corresponding values of 4.87, 7.53 and 10.19%, and at 15-30 cm depth it was recorded as 1.07, 2.80 and 5.43%, respectively (Table 5). In conventional soil fertilization, available N were recorded as 124.20, 124.06 and 124.00 mg/kg at 0, 15 and 30 cm distance from the emitters, respectively. These findings are in line with Haynes and Swift (1987) who also reported that maximum of ammonium N in the top soil with its decrease when away from the emitters. Moreover, these results indicated that available N under drip fertigation was highest below the emitting point and decreased consistently with increase of lateral distance from emitter up to 30 cm. The lateral distribution in T_5 was uniform at different distances from the trunk of the tree. Earlier studies revealed that the lateral N distribution under fertigation was governed by the movement of water in the soil profile (Raina *et al.* 2005). Similarly, depth-wise available P distribution indicated its progressive decrease with increasing soil depth. The data presented on the lateral movement of available P revealed that T_4 exhibited 23.92, 21.12 and 16.72 mg/kg at 0, 15 and 30 cm at lateral distance from emitters, respectively. The immobile nature of P coupled with the fixation and/or the conversion to non-soluble form has contributed to higher P in the surface layer compared to sub-surface layers (Bhat *et al.* 2007, Badr 2007). Neilsen *et al.* (2008) also reported comparatively better movement of P under fertigation than soil application. Further, they also reported a consistent decrease of P with decrease in fertilization rate. Considering all the treatments, available K was recorded as 141.21 and 131.35 mg/kg at 0-15 and 15-30 cm soil depth, respectively, and 133.09, 123.41 and 127.81, 117.73 mg/kg at 15 and 30 cm distance from emitters, respectively. The per cent increase in available K compared to T_5 at 0-15 cm soil depth was recorded 11.44, 12.97 and 14.55 mg/kg in T_2, T_3 and T_4, respectively. Likewise, the per cent increase over T_5 at 15-30 cm depth was 12.49, 13.56 and 15.60 mg/kg in T_2, T_3 and T_4, respectively. It is further inferred that lateral distribution of K varied markedly under different fertigation levels and exhibited a positive relationship with the dose of fertilizer applied. These results are also according to Uriu *et al.* (1980) who observed a positive correlation between fertigated K and available K content in soil. Depth-wise distribution of exchangeable Ca indicated that it decreased with the increase of soil depth up to 30 cm which ascribed to the concentration of both Ca and Mg in soil reduced under the different levels of urea fertigation. Fertilization with conventional soil application registered maximum exchangeable Ca content (25.6 mg/kg) in 0-15 cm depth, whereas, minimum Ca (20.5 mg/kg) was noticed under fertigation with T_4. Similar trend was also noticed in 15-30 cm soil depth. Highest exchangeable Ca (24.77 mg/kg) at 0-15 and 15-30 cm soil depth was recorded at T_5, closely followed by T_1 and the least (19.44%) was recorded in T_4. Similarly, the exchangeable Mg content also decreased with increased soil depth. Considering average data of all the treatments, the exchangeable Mg content was 21.62 and 19.85 mg/kg in the 0-15 and 15-30 cm soil depths, respectively (Table 4). Fertilization in T_5 registered maximum exchangeable Mg content (22.89 mg/kg) in 0-15 cm depth, whereas, minimum (19.99 mg/kg) was noticed under fertigation with T_4. Similar trend was also noticed in 15-30 cm soil depth. The present studies revealed that the concentration of both Ca and Mg were reduced with corresponding decrease in the dose of urea fertigation. These findings are also conformity with those of Belton and Goh

Table 5 Depth-wise distribution of exchangeable Ca, Mg and micronutrient cations of soil of Snow Queen nectarines

Treatment	Depth (cm)	Exchangeable Ca (mg/kg)	Exchangeable Mg (mg/kg)	Micronutrients (mg/kg)			
				Fe	Cu	Zn	Mn
T_1	0-15	25.10 (1.95)	22.76 (0.57)	49.62 (1.39)	1.38 (7.38)	1.43 (1.38)	38.20 (4.98)
	15-30	23.74 (0.79)	20.72 (0.77)	47.44 (5.52)	1.21 (8.33)	1.39 (0.71)	36.49 (4.28)
T_2	0-15	24.13 (5.74)	22.01 (3.84)	52.61 (4.44)	1.68 (12.75)	1.64 (13.10)	41.42 (3.03)
	15-30	22.57 (5.93)	20.54 (1.63)	51.40 (2.37)	1.60 (21.21)	1.47 (5.00)	39.37 (3.28)
T_3	0-15	22.02 (13.98)	20.43 (10.75)	54.12 (7.55)	1.90 (27.52)	1.65 (13.79)	42.95 (6.84)
	15-30	20.30 (15.83)	18.86 (9.67)	53.09 (5.74)	1.71 (29.55)	1.53 (9.29)	41.27 (8.26)
T_4	0-15	20.50 (19.92)	19.99 (12.67)	55.09 (9.48)	2.32 (55.70)	1.67 (15.17)	43.40 (7.96)
	15-30	18.39 (23.15)	18.26 (12.55)	54.69 (8.92)	2.08 (57.58)	1.56 (11.43)	41.64 (9.23)
Control	0-15	25.60	22.89	50.32	1.49	1.45	40.20
	15-30	23.93	20.88	50.21	1.32	1.40	38.12

Figures in parentheses are percent increase or decrease over control

Table 6 Effect of nitrogen fertigation on leaf nutrient content of Snow Queen nectarines

Treatment	Macronutrients (%)			Ca (%)	Mg (%)	Micronutrients (mg/kg)			
	N	P	K			Fe	Cu	Zn	Mn
T_1	3.05 (3.17)	0.13 (31.58)	2.4 (8.75)	2.42 (1.22)	0.73 (5.19)	244.99 (0.14)	11.41 (0.17)	27.27 (0.58)	58.22 (0.41)
T_2	3.45 (9.52)	0.25 (31.58)	2.87 (9.13)	2.39 (2.45)	0.68 (11.69)	247.48 (0.88)	12.3 (7.61)	28.55 (4.08)	59.21 (1.28)
T_3	3.59 (13.97)	0.27 (42.11)	2.98 (13.31)	2.35 (4.08)	0.65 (15.58)	247.77 (0.99)	12.33 (7.87)	28.66 (4.48)	60.84 (4.07)
T_4	3.64 (15.56)	0.3 (57.89)	3.11 (18.25)	2.31 (5.71)	0.63 (18.18)	247.86 (1.03)	12.34 (7.96)	28.73 (4.74)	60.88 (4.14)
Control	3.15	0.19	2.63	2.45	0.77	245.33	11.43	27.43	58.46
LSD (P=0.05)	0.28	0.05	0.32	NS	NS	0.29	0.02	0.34	0.11

Figures in parentheses are percent increase or decrease over control

(1992) who also reported that an increase of urea in fertigation reduced the exchangeable Ca and Mg due the acidification effect of urea applied. The distribution of available Fe under different fertigation treatments and conventional soil fertilization are cited in Table 5. Depth-wise distribution of available Fe revealed that its content decreased with increasing soil depth. Fertigation in T_2, T_3 and T_4 increased Fe by 4.44, 7.55 and 9.48 per cent, respectively in the 0-15 cm soil depth. Maximum Fe content (54.89 mg/kg) was recorded in T_4 followed by T_3, while, minimum (48.53 mg/kg) was recorded in T_1. Similarly, available Cu, Zn and Mn content also decreased with increased soil depth. In the present investigation, DTPA-extractable Fe, Cu, Zn and Mn cations increased significantly with different levels of N fertigation. The present findings are in line with that of Haynes (1988) who also reported increased concentration of DTPA extractable Zn, Cu, Fe and Mn cations in soil with increased application rate of urea-N rate through fertigation.

Leaf nutrient concentartion

Leaf N content increased with the increase in different levels of N fertigation. Maximum leaf N (3.64%) was recorded in T_4, which was significantly higher than T_1 and T_5, but statistically similar to T_3 and T_2. There was 9.52, 13.97, 15.56% increase and 3.17% decrease in leaf N under T_2, T_3, T_4 and T_1, respectively, over T_5 (Table 6). Similarly, highest leaf P (0.30%) was accumulated in the leaves of the trees which were fertigated with T_4, and were statistically similar to T_3 and T_2. There was increase of 31.58, 42.11, 57.89%, and 31.58% of decrease in T_2, T_3, T_4 and T_1, respectively, over T_5. Maximum leaf K (3.11%) was registered in T_4. The content was further 9.13, 13.31, 18.25% increase and 8.75% decrease in the treatments T_2, T_3, T_4 and T_1 over T_5, respectively. Similar increase in leaf nutrient content with application of higher dose of fertilizers has been reported by Murthy *et al.* (2001) and Neilsen *et al.* (2004). It is also evident from the data that different levels of N fertigation exhibited no significant effect on the leaf Ca and Mg content. In the present investigation, leaf micronutrient cations (Fe, Cu, Zn and Mn) were in optimum range among different treatments applied. Kwong (1973) and Leece (1976) observed that the increased N application improved the uptake of Fe, Cu, Zn and Mn content, while, leaf Ca and Mg contents were decreased.

It was concluded that nitrogen fertigation at 75% of the recommended dose of fertilizers significantly improved plant growth attributes, vertical and horizontal distribution of macro- and micronutrient cations in the rhizosphere soil and its uptake in leaf and fruit quality attributes of Snow Queen nectarines trees which saved 25% of the inorganic fertilizers application compared to traditional soil fertilization.

REFERENCES

AOAC. 1980. *Official Methods of Analysis of the Associations of Analytical Chemists,* 13th edition, pp 376–84. Benjamin Franklin Station, Washington, DC.

Ahmad M F, Samanta A and Jabeen A. 2010. Response of sweet cherry (*Prunus avium*) to fertigation of nitrogen, phosphorus and potassium under Kerawa land of Kashmir valley. *Indian Journal of Agricultural Sciences*. **80** (6): 512–6.

Anonymous. 2007. *Annual Report, Directorate of Horticulture, Shimla, Himachal Pradesh*.

Badr M A. 2007. Spatial distribution of water and nutrients in root zone under surface and subsurface drip irrigation and cantaloupe yield. *World Journal of Agricultural Sciences* **3** (6): 747–56.

Battilani A. 1997. Effect of irrigation and fertigation on the yields and market quality of nectarines. (In) Proceedings of 2nd International Symposium on Irrigation of Horticultural Crops. *Acta Horticulturae* **449** (1): 153–9.

Belton P R and Goh K M. 1992. Effect of urea fertigation in apple trees on soil pH, exchangeable cations and extractable manganese in a sandy loam soil in New Zealand. *Fertilizer Research* **33** (3): 239–47.

Bhat R, Sujatha S and Balasimha D. 2007. Impact of fertigation on productivity of arecanut (*Areca catechu* L.). *Agricultural Water Management* **90** (1-2): 101–11.

Buban T and Lakatos T. 2000. Fertigation in young apple orchards by using different forms of nitrogen. *Acta Horticulturae* **525**: 201–7.

Chapman H D. 1964. Suggested foliar sampling and handling techniques for determining the nutrient status of some field, horticultural and plantation crops. *Indian Journal of*

Horticulture **21**: 97–119.

Halfacre R G, Baradent J A and Rollens, Jr. H A. 1968. Effect of Alar on morphology, chlorophyll contents and net CO_2 assimilation rate of young apple trees. *Proceedings of American Society for Horticulture Science* **93**: 40–52.

Haynes R J. 1985. Principles of fertilizer use in trickle irrigated crops. *Fertilizer Research* **6**: 235–55.

Haynes R J. 1988. Comparison of fertigation with broadcast applications of urea-N on levels of available soil nutrients and on growth and yield of trickle irrigated peppers. *Scientia Horticulturae* **35**: 189–98.

Hlusek J, Hrebikova H and Hrivna I. 1993. The effect of different forms of nitrogen on the chlorophyll content of leaves of apple trees. *Zahradnictvi* **20** (2): 65–71.

Jackson M L. 1973. *Soil Chemical Analysis*. Prentice Hall India Pvt Ltd, New Delhi.

Jackson M L. 2005. *Soil Chemical Analysis,* p 925. Parallel Press, University of Wisconsin, Madison, Wisconsin, USA.

Jia H J, Hirano K and Okamoto G. 1999. Effects of fertilizer levels on tree growth and fruit quality of 'Hakuho' peaches (*Prunus persica*). *Journal of the Japanese Society for Horticultural Science* **68**: 487–93.

Kumar D and Pandey V. 2008. Effect of NPK fertigation on growth, yield and quality of banana 'Rasthali' (AAB-Pathkapoora) in coastal agro-climatic conditions of eastern India. *Indian Journal of Agricultural Sciences* **78** (9): 798–800.

Kwong S S. 1973. Nitrogen and potassium fertilization effects on yield, fruit quality and leaf composition of 'Stanley' prunes. *Journal of the American Society for Horticultural Sciences* **98** (1): 72–4.

Leece D R. 1976. Diagnostic leaf analysis for stone fruit. Effects of fertilizers nitrogen, phosphorus and potassium on leaf composition of peach. *Australian Journal of Experimental Agricultural and Animal Husbandry* **16** (2): 775–9.

Lindsay W H and Norvell W A. 1978. Development of DTPA soil test for Zn, Fe, Mn and Cu. *Soil Science Society of America Journal* **42**: 420–8.

Melgar J C, Schumann A W and Syvertsen J P. 2010. Fertigation frequency affects growth and water and nitrogen use efficiencies of Swingle Citrumelo citrus rootstock seedlings. *Hort Science* **45** (8): 1 255–9.

Merwin H D and Peach P M. 1951. Exchangeability of soil potassium in the sand, slit and clay fractions as influenced by the nature of complementary exchangeable cations. *Proceedings of the American Soil Science Society* **15**: 125–6.

Murthy P V, Khan M M, Nachegowda,V and Umamahes W P. 2001. Effect of fertigation on leaf area and leaf petiole nutrient contents in Bangalore Blue grapes. *Current Research, University of Agricultural Sciences, Bangalore* **30**: 14–6.

Neilsen G H, Kappel F, Toivonen P and Neilsen D. 2008. A closer look at P and water management on productivity of apple and sweet cheery. *Fluid Journal* **16** (3): 61.

Neilsen G H, Neilsen D L, Herbert C and Hogue, E J. 2004. Response of apple to fertigation of N and K under conditions susceptible to the development of K deficiency. *Journal of the American Society for Horticultural Science* **129** (1): 26–31.

NHB. 2000. Area and production estimates for horticulture crops. http://www.nbh.gov.in/statististics/area-production-statististics.html.

Olsen S R, Cole C V, Watanabe F S and Dean L A. 1954. Estimation of available phosphorusby extraction with sodium bicarbonate. USDA Circular 939.

Panse V G and Sukhatme P V. 1989. *Statistical Methods of Agricultural Workers*. Indian Council of Agricultural Research, New Delhi.

Raina J N, Thakur B C, Suman S and Spehia R S. 2005. Effect of fertigation through drip system on nitrogen dynamics, growth, yield and quality of apricot. *Acta Horticulturae* **696**: 227–31.

Raina J N. 2000. Drip irrigation and fertigation in vegetable crops. (*In*) *Horticulture Technology-II*, pp 339–46. Sharma V K and Azad K C (Eds). Deep and Deep Publications, New Delhi.

Rao K D and Subramanyam K. 2009. Effect of nitrogen fertigation on growth and yield of pomegranate var. Murdula under low rain fall zone. *Agriculture Science Digest* **29** (2): 1–3.

Reddy B M C, Srinivas K, Padma P and Raghupathi H B. 2002. Response of Robusta banana to N and K fertigation. *Indian Journal of Horticulture* **59**: 342–48.

Sharma S K. 1994. 'Studies on nutrient removal by plum (cv. Santa Rosa) trees at different levels of nitrogen'. M Sc thesis, Dr Y S Parmar University of Horticulture and Forestry, Solan.

Singh B P, Dimri D C and Singh S C. 2007. Efficacy of NPK management through fertigation on growth characteristics of apple (*Malus domestica* Bork) plant. *Pantnagar Journal of Research* **5**: 50–3.

Solaimalai A, Baskar M, Sadasakthi A and Subburamu K. 2005. Fertigation in high value crops. *Agriculture Review* **26**: 1–13

Subbjah B V and Asija G L. 1956. A rapid procedure for the examination of available nitrogen in soil. *Current Science* **25**: 259–60.

Treder W. 2006. Influence of fertigation with nitrogen and a complete fertilizer on growth and yielding of Gala apple trees. *Journal of fruit and Ornamental Plant Research* **14**: 143–54.

Uriu K, Carlson R M, Henderson D W, Schulbach H and Aldrich T M. 1980. Potassium fertigation of prune trees under drip irrigation. *Journal of the American Society for Horticultural Science* **105** (4): 508-10.

Walkley A and Black C A. 1934. An examination of the method for determining soil organic matter and proposed modification of chromic and titration method. *Soil Science* **36**: 29–39.

Westwood M N. 1993. Temperate Zone Pomology, p 223. Timber Press, Portland, Oregon.