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EFFECT OF FERTIGATION ON PRODUCTIVITY AND QUALITY ATTRIBUTES OF APPLE CV. FUJI ZHEN AZTEC UNDER HIGH-DENSITY PLANTING SYSTEM

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ABSTRACT

The present research "Effect of Fertigation on Productivity and Quality Attributes o of Apple cv. Fuji Zhen Aztec under High-Density Planting System" was conducted during 2024 at the Division of Fruit Science, SKUAST-K, Shalimar, Srinagar. The experiment was conducted on 13-year-old apple trees of cv. Fuji Zhen Aztec grafted on M9-T337 under a high-density planting system (1.5 × 3 m). A total of nine fertigation treatments comprising four NPK levels (120, 100, 80 and 60% RDF) were applied at 7- and 14-day intervals, along with a conventional soil application control, and was evaluated by a Randomized Complete Block Design with three replications in each treatment. The results showed that fertigation significantly influenced the yield and fruit quality attributes of apple. Application of 120% RDF at 7-day intervals recorded maximum fruit yield (20.8 kg tree^{-1}), yield efficiency (0.246 kg cm^{-2}), fruit weight (201.35 g), fruit diameter (76.95 mm), TSS (13.65 °Brix), total sugars (10.95%), anthocyanin content (34.70 mg 100 g^{-1}) and Grade-A fruits (86.8%), while maximum fruit firmness (8.94 kg cm^{-2}) was observed under 60% RDF at 14-day intervals. The treatment of 120% RDF at 14-day intervals and 100% RDF at 7-day intervals were statistically at par with each other. The control recorded the lowest values for all parameters. While considering the performance and economic feasibility, fertigation with 100% RDF at 7-day intervals was found to be the most suitable strategy for enhancing yield and fruit quality of apple cv. Fuji Zhen Aztec under temperate conditions of Jammu and Kashmir
Keywords **:** Fuji Zhen Aztec, M9-T337 high density planting, fertigation, nutrient management.

Introduction

Apple (*Malus* × *domestica* Borkh.) the premier table fruit of the temperate world, also known as the king of the temperate fruits, is a cross-pollinated fruit crop, that belongs to the genus Malus of the family Roseaceae and order Rosales (Rather *et al.*, 2024) It is a heterozygous, cross-pollinated, diploid species with a basic chromosome number of x = 17. Renowned for its nutritional value, flavor, and long storage life, the apple ranks among the most consumed fruits globally and holds immense economic significance in temperate regions. In India, apple cultivation has emerged as a vital horticultural enterprise, contributing significantly to the rural economy, employment generation, and export earnings. The crop occupies approximately 315,000 hectares with an annual production of 2.437 million metric tonnes (FAOSTAT, 2024). Jammu and Kashmir continues to dominate national apple production, accounting for nearly 70% of the total output, followed by Himachal Pradesh and Uttarakhand. The cultivation of high-value cultivars such as Fuji, Gala, Golden Delicious, and Red Delicious has gained prominence due to their superior market demand and consumer preference.

To meet the growing demand and enhance productivity per unit area, there has been a rapid shift towards high-density planting (HDP) systems in apple orchards. HDP, characterised by planting densities ranging from 1,000 to over 5,000 trees per hectare, offers several advantages, including early bearing, higher yields, better utilisation of resources, and ease of mechanisation (Kumar and Haroon, 2021; Ladon *et*

al., 2022). However, the success of HDP systems heavily depends on the precise and efficient management of water and nutrients called as fertigation. The concurrent application of water-soluble fertilisers through drip irrigation, has emerged as a modern, sustainable, and highly efficient alternative. This technique enables the delivery of precise quantities of nutrients directly to the active root zone at critical growth stages, synchronising nutrient supply with plant demand (Shirgure *et al.*, 2001; Neilsen and Neilsen, 2002; Rakicevic *et al.*, 2012). It improves nutrient uptake efficiency, minimises losses, reduces fertiliser requirements, and promotes uniform growth. It also supports better water-use efficiency, which is particularly important in the changing climatic scenario with erratic rainfall patterns and depleting water resources in the Himalayan regions (Suman, 2011; Thakur *et al.*, 2020). Several studies have documented the beneficial effects of fertigation on apple productivity and fruit quality attributes. Improved tree growth, higher fruit set, increased yield, better fruit size, colour, soluble solids content, and enhanced shelf life have been reported under optimised fertigation schedules (Banyal and Sharma, 2011; Kumar and Haroon, 2021; Ladon *et al.*, 2022; Mason *et al.*, 2018; Chauhan *et al.*, 2006; Singh *et al.*, 2007; Verma *et al.*, 2017). Despite these advancements, information on the optimal doses and timing of NPK fertigation specific to high-density orchards of cv. Fuji Zhen Aztec, a promising colored Fuji clone, remains limited under Jammu and Kashmir conditions. Therefore, the investigation was undertaken with the objective of evaluating the influence of different doses and timings of NPK fertigation on growth, yield, and quality attributes of the apple cv. Fuji Zhen Aztec under a high-density orcharding system.

Materials and Methods

The current experiment was conducted during the year 2024 at the Experimental Farm of the Division of Fruit Science, SKUAST-K, Shalimar, Srinagar. Thirteen-year-old uniform trees of the apple cv. Fuji Zhen Aztec grafted on M9-T337 rootstock were selected for the study. The experiment was laid out in a Randomized Complete Block Design (RCBD) with nine treatments and three replications.

The recommended dose of fertilisers (RDF) was 225 g N, 125 g P_2O_5 and 300 g K_2O per tree. In fertigation treatments, 25% RDF was applied as a basal soil dose two weeks before bloom, and the remaining 75% was supplied through drip irrigation (two emitters per tree^{-1} @ 2.2 L h^{-1}) using urea, MAP and SOP from full bloom to one month before harvest.

Table 1 : Treatment details and split dosage details

Treatment	Treatment Combination
T_1: Control (soil application with RDF)	Urea (381g/tree) DAP (271g/tree) MOP (500g/tree)
T_2:120%RDF@ 7 DAYS INTERVAL	22 split doses: **Urea**(18g/tree), **MAP** (9g/tree), **SOP** (25g/tree)
T_3: 120%RDF@14DAYS INTERVAL	11 split doses: **Urea** (36g/tree), **MAP** (18g/tree), **SOP** (50g/tree)
T_4: 100%RDF @ 7 DAYS INTERVAL	22 split doses: **Urea** (15g/tree), **MAP** (7g/tree), **SOP** (20g/tree)
T_5: 100%RDF@14 DAYS INTERVAL	11 split doses **Urea**: (30g/tree) **MAP** (14g/tree), **SOP** (40g/tree)
T_6: 80%RDF @ 7 DAYS INTERVAL	22 split doses **Urea**: (12g/tree) **MAP** (6g/tree), **SOP (**16g/tree)
T_7: 80% RDF@ 14 DAYS INTERVAL	11 split doses **Urea**: (24g/tree) **MAP** (12g/tree), SOP (32g/tree)
T_8: 60%RDF @ 7 DAYS INTERVAL	22 split doses **Urea**: (9g/tree) **MAP** (4g/tree), SOP (12g/tree)
T_9: 60% RDF @14 DAYS INTERVAL	11 split doses: **Urea** (18g/tree), **MAP** (8g/tree), **SOP** (24g/tree)

Parameters

Data was recorded on the following parameters:

(a) Yield per tree (kg): Total fruit yield per tree was recorded at harvest by weighing all marketable fruits from each experimental tree using an electronic balance and expressed in kilograms per tree.

(b) Yield efficiency (kg cm^{-2}): Trunk cross-sectional area (TCSA) was calculated from trunk circumference measured at 15 cm above the graft union. TCSA was computed using the formula:

$$\text{TCSA (cm}^2\text{)} = \frac{[\text{Circumference (cm)}]^2}{(4\pi)}$$

$$\text{Yield efficiency (kg cm}^{-2}\text{)} = \frac{\text{Fruit yield per tree (kg)}}{\text{TCSA (cm}^2\text{)}}$$

(Westwood, 1978).

a) **Fruit physical parameters:** Twenty fruits per tree were randomly selected for recording physical parameters.

b) **Fruit length (mm) and Fruit diameter (mm**): Measured using a digital Vernier calliper (accuracy 0.01 mm) at polar and equatorial positions, respectively.

c) **Fruit weight** (g): Individual fruit weight was recorded using a digital electronic balance (precision ± 0.1 g), and the average weight was calculated.

d) **Fruit firmness (kg cm^{-2}):** Determined using an Effigy penetrometer (Model FT-3-27) with a 7/16-inch (11 mm) plunger. Measurements were taken at three equidistant points on the equatorial region after removing a small peel area. Penetration depth

was 5/6 inch, and the average of readings was recorded (Westwood, 1978).

Fruit chemical parameters

a. **Total Soluble Solids (°Brix):** Determined using a digital/Zeiss hand refractometer. A few drops of fresh juice from the equatorial portion were placed on the prism, and readings were recorded at room temperature (Ranganna, 1986).
b. **Titratable Acidity (% malic acid):** 10 g of fruit pulp was homogenised and diluted to 100 ml. A 10 ml aliquot was titrated against 0.1 N NaOH using phenolphthalein as an indicator. Acidity was expressed as per cent malic acid (Ranganna, 1986).
c. **Total Sugars (%):** Determined by the Lane and Eynon volumetric method using Fehling's solution after clarification and acid hydrolysis of the sample (Ranganna, 1986).
d. **Anthocyanin content (mg 100 g^{-1}):** Extracted with ethanolic HCl (85:15 v/v of 95% ethanol and 1.5 N HCl). Absorbance was measured at 540 nm using a spectrophotometer. Total anthocyanin was calculated using the formula: Total anthocyanin (mg 100 g^{-1}) = (Total O.D. × 100) / 98.2 (Ranganna,1986; Kaur and Dhillon, 2007).

Results and Discussion

The data about the effect of different doses and timings of NPK fertigation on the yield and quality parameters of the apple cv. Fuji Zhen Aztec under a high-density orcharding system are presented in Tables 2 and 3. The results revealed that fertigation doses (60%, 80%, 100%, and 120% RDF) and application intervals (7 and 14 days) significantly influenced almost all the parameters studied, indicating the importance of precise nutrient management in intensive apple production (Chauhan *et al.*, 2006; Singh *et al.*, 2007; Thakur *et al.*, 2020).

Fruit Yield and Yield Efficiency Fertigation treatments significantly enhanced fruit yield and yield efficiency compared to conventional soil application. The highest fruit yield (20.8 kg $tree^{-1}$) and yield efficiency (0.246 kg cm^{-2}) were recorded in T_2 (120% RDF applied at 7-day intervals). This treatment was statistically at par with T_3 (120% RDF at 14-day intervals, 20.7 kg $tree^{-1}$ and 0.245 kg cm^{-2}) and T_4 (100% RDF at 7-day intervals, 19.6 kg $tree^{-1}$ and 0.232 kg cm^{-2}). The control treatment (T_1-100% RDF through soil application) recorded the lowest fruit yield (14.0 kg $tree^{-1}$) and yield efficiency (0.166 kg cm^{-2}). The substantial increase in yield and yield efficiency under higher fertigation doses with frequent application can be attributed to improved nutrient availability and uptake during critical phenological stages (flowering, fruit set, and fruit development). Split application of nutrients through drip irrigation minimised leaching losses, reduced nutrient fixation in the soil, and maintained optimal nutrient concentration in the root zone, leading to better assimilate production and partitioning towards fruit growth (Suman, 2011; Rakicevic *et al.*, 2012; Verma *et al.*, 2017). Frequent fertigation (7-day interval) ensured a continuous supply of nutrients, which synchronised with the high demand periods of the crop, resulting in higher fruit retention and ultimately higher productivity. These findings are in agreement with Kumar and Haroon (2021), Ladon *et al.* (2022), Banyal and Sharma (2011), Mason *et al.* (2018), Thakur *et al.* (2020), Robinson and Stiles (2004), and Raina *et al.* (2011).

Fruit Physical Parameters

Fertigation had a marked positive effect on fruit physical quality attributes. The maximum fruit length (69.70 mm), fruit diameter (76.95 mm), and fruit weight (201.35 g) were recorded in T_2 (120% RDF at 7 days), which remained statistically at par with T_3 and T_4. The control treatment (T_1) produced the smallest and lightest fruits (67.23 mm diameter and 172.56 g weight).The improvement in fruit size and weight under higher and more frequent fertigation treatments was due to enhanced cell division and cell enlargement facilitated by balanced and timely supply of nitrogen, phosphorus, and potassium. Potassium, in particular, plays a vital role in carbohydrate translocation and water uptake into the fruit, resulting in larger fruit size (Park *et al.*, 2004; Banyal and Sharma, 2011; Suman, 2011; Kumar and Haroon, 2021). Regarding fruit firmness, the highest value (8.94 kg cm^{-2}) was recorded in T_9 (60% RDF at 14-day intervals), while the lowest firmness (8.50 kg cm^{-2}) was observed in T_2. The reduction in firmness at higher fertigation doses and frequent intervals is attributed to larger fruit size (dilution effect) and the antagonistic effect of high potassium on calcium uptake, which weakens cell wall strength (Neilsen and Neilsen, 2004; Porro *et al.*, 2013). This inverse relationship between fruit size and firmness is well documented in apples.

Fruit Chemical Parameters

Fertigation treatments significantly improved the chemical quality of fruits. The highest Total Soluble Solids (13.65 °Brix), total sugars (10.95%), and anthocyanin content (34.70 mg 100 g^{-1}) were recorded in T_2, which was statistically at par with T_3 and T_4. The control treatment recorded the lowest values for these parameters (11.89 °Brix, 9.51%, and 26.00 mg

100 g^{-1}, respectively). Titratable acidity was highest in the control (0.59%) and lowest in T_2 (0.41%).

The enhancement in TSS, total sugars, and anthocyanin content under higher fertigation levels with frequent application is attributed to improved photosynthetic efficiency, better carbohydrate synthesis, and efficient translocation of photosynthates to the developing fruits. Adequate potassium supply through fertigation promotes the conversion of starch into soluble sugars and enhances the activity of enzymes involved in pigment (anthocyanin) biosynthesis, leading to superior fruit colour and sweetness, an important quality attributes for Fuji apples (Nielsen *et al.*, 2001; Park *et al.*, 2004; Karuna *et al.*, 2017; Mason *et al.*, 2018). The decrease in titratable acidity with increasing fertigation doses may be due to higher metabolic conversion of organic acids into sugars during fruit ripening. These results conform with the findings of Karuna *et al.* (2017), Mason *et al.* (2018), Park *et al.* (2004), Kuchanwar *et al.* (2017), and Kachwaya and Chandel (2015).

Table 2: Effect of different doses and timings of fertigation on fruit yield, yield efficiency and physical parameters of apple cv. Fuji Zhen Aztec

Treatment	Yield (kg/tree^{-1})	Yield efficiency (kg cm^{-2})	Fruit weight (g)	Fruit diameter (mm)	Fruit firmness (kg cm^{-2})
T_1 (Control)	14.0	0.166	172.56	67.23	8.90
T_2 (120%RDF @7d)	20.8	0.246	201.35	76.95	8.50
T_3 (120% RDF@14d)	20.7	0.245	201.25	76.85	8.51
T_4 (100%RDF @7d)	19.6	0.232	201.20	76.80	8.52
T_5 (100%RDF @14d)	19.3	0.228	197.90	73.93	8.68
T_6 (80% RDF@7d)	18.5	0.219	188.40	73.36	8.73
T_7 (80%RDF @14d)	18.0	0.213	183.10	72.97	8.79
T_8 (60% RDF@7d)	16.5	0.195	178.80	70.68	8.91
T_9 (60%RDF @14d)	16.0	0.189	177.60	69.98	8.94
C.D. ($p \leq 0.05$)	0.067	0.003	0.167	0.066	0.033

Table 3: Effect of different doses and timings of fertigation on fruit chemical parameters of apple cv. Fuji Zhen Aztec

Treatment	TSS (°Brix)	Total sugars (%)	Titratable acidity (%)	Anthocyanin (mg 100 g^{-1})
T_1 (Control)	11.89	9.51	0.59	26.00
T_2 (120%RDF @7d)	13.65	10.95	0.41	34.70
T_3 (120%RDF @14d)	13.63	10.94	0.42	34.68
T_4 (100%RDF @7d)	13.62	10.93	0.43	34.67
T_5 (100% RDF@14d)	13.30	10.64	0.46	33.37
T_6 (80% RDF@7d)	13.10	10.48	0.48	31.22
T_7 (80%RDF @14d)	12.80	10.24	0.50	30.22
T_8 (60%RDF @7d)	12.40	9.92	0.52	29.22
T_9 (60%RDF @14d)	12.00	9.60	0.57	28.22
C.D. ($p \leq 0.05$)	0.008	0.014	0.005	0.033

Conclusion

The current experiment demonstrated the positive effects of different doses and timings of NPK fertigation on yield and quality parameters of high-density apple cv. Fuji Zhen Aztec. Fertigation with 120% RDF applied at 7-day intervals recorded the highest fruit yield, yield efficiency, fruit weight, fruit diameter, TSS, total sugars, and anthocyanin content, which was statistically at par with 100% RDF applied at 7-day intervals. Fruit firmness was highest under lower fertigation doses. Thus, application of 100% RDF through fertigation at 7-day intervals can be recommended for improving the yield and quality of the apple cv. Fuji Zhen Aztec under high-density orcharding conditions in the Kashmir valley. This schedule offers an excellent balance between productivity and fruit quality while promoting efficient nutrient use.

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