

# Effect of Foliar Application of Nitrogen, Phosphorus and Iron on Growth Characteristics of Apple cv. 'Golden Delicious'

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## Summary

Nitrogen, phosphorus, and Fe are essential elements in plants. Alkaline pH, high concentrations of calcium, and bicarbonate ions in calcareous soils stabilize and reduce the solubility of these elements, thus reducing their absorption and transfer from the roots to different parts of the plant. This study was conducted to investigate the effect of nitrogen, Fe and P foliar application on the growth characteristics of 'Golden Delicious' cultivar in a randomized complete block design with three replications in 2019. Treatments included foliar application of urea (0, 1, and 2%), Fe (0, 1.5, and 3 g·L<sup>-1</sup>), and P (0, 16, and 32 ppm), and were applied to 4-year-old apple trees cv. 'Golden Delicious'. At the end of the study, the length, diameter, number of fruits, leaf chlorophyll content, shoot length, leaf area, plant height, and leaf concentrations of P, Fe, and nitrogen were measured. The results showed that the effect of foliar application of urea on the leaf concentrations of nitrogen, Fe, and P, shoot length, and plant height was effective. The effects of foliar application of P on nitrogen, Fe and P, fruit length, fruit diameter, and leaf chlorophyll were significant. Foliar application of Fe also had a significant effect on the leaf concentration of Fe and N, and these traits increased to 4.74 and 28.07, respectively, compared to the control. The effect of the interaction of these elements on the leaf concentrations of nitrogen, Fe, and P, as well as fruit length, fruit diameter, and shoot length, was significant and increased these traits compared with the control. Based on these results, foliar application of these elements can be recommended as a complementary method to enhance the growth of apple trees cv. 'Golden Delicious'.

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## Key words

calcareous soils, element concentration, leaf area, *Malus domestica*, pome fruits

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## Introduction

Most of Iran's regions are covered with calcareous soils, and because of the lack of organic matter and nutrients and high pH, mass production of agricultural products in these regions is difficult. Alkaline pH, high concentrations of calcium ions, and the production of large amounts of bicarbonate ions in these soils have caused some nutrients to become insoluble and unusable for the plant; in the case of absorption, due to the increase in the pH of the plant tissue, they will decrease the metabolism of the plant (Hejazi and Kafashi Sedghi, 2008). Therefore, foliar spraying can be used when the absorption of nutrients through the roots is limited (Nasrolahzadehasl et al., 2017). Foliar spraying is recommended as an effective method for increasing mineral nutrients in plant tissues and reducing adverse environmental effects (Souri, 2016; Dehnavard et al., 2017). This method causes rapid absorption of nutrients from the leaves and minimizes groundwater and environmental pollution (Liu and Lal, 2015).

Apple (*Malus domestica* Borkh), which belongs to the Rosaceae family, is one of the most important products in temperate regions. This fruit, along with its products, has the most global trade among orchard fruits and plays an important role in the economic prosperity of gardeners (Wang et al., 2014). Apples with large amounts of antioxidant compounds, sugars, vitamins, minerals, and fibers are very important for human health (Tahir, 2006). Improving apple trees using nutrients based on their needs increases their performance and quality (Soest, 2012). Apple cultivation is of major agricultural and economic importance in Iran, ranking among the top apple-producing countries worldwide. Annual production ranges from 3.8 to 5.2 million tons across 250,000–296,000 hectares, with West Azerbaijan, East Azerbaijan, and Tehran provinces being the main production regions. The Damavand area is particularly renowned for high-yield and high-quality apples. Iran exports 700,000–925,000 tons annually to markets including India, Russia, Iraq and the Gulf states, generating significant revenue. Scientific studies on cultivar diversity and local adaptation highlight the critical role of apple cultivation in sustaining agricultural development and ensuring regional food security (Rezaee et al., 2017; FAO, 2023).

Nitrogen is another widely consumed food element that plays an important role in biochemical and physiological reactions of plants, such as plant growth and performance, photosynthesis and fruit quality (Al-Tawaha et al., 2018). Nitrogen deficiency reduces fruit growth and yield, and increases early leaf fall (Ernarni, 2008). Among the different forms of nitrogen fertilizer, urea has the highest rate of absorption (up to 70%) and penetration into plant leaves (Huett and Vimpany, 2006). Foliar spraying of urea at the right time and at the right concentration has an important effect on the quantitative and qualitative characteristics of plants and minimizes the adverse effects caused by its excessive use in the soil, which poses a serious risk to underground water and human health (Kheirabadi, 2013). Another essential plant element is P, which is required to complete the life cycle and healthy growth of the plant. Soil characteristics, such as high pH and low organic matter, strongly stabilize P and lead to a decrease in the absorbable P concentration (Ardalan and Savaghebi, 2009). This widely used element plays a role in many physiological processes, such as photosynthesis and enzymatic activities of the plant, and

its deficiency causes the growth and performance of the plant to decrease significantly (Khan et al., 2009). Foliar application of P causes almost complete absorption of this element (Pandey et al., 2013).

Fe is one of the micro-elements for plants, and plays a role in many biochemical and physiological processes of plants, such as the regulation of enzyme activity and chlorophyll production. Apple trees are sensitive to Fe deficiency (Tabatabaei, 2013). Unfavorable soil conditions, such as high pH, have caused it to become unabsorbable by plant roots despite the presence of high amounts of this element in the soil (Rangel et al., 2011). Therefore, it is necessary to make Fe required by the plant available to the plant in a soluble form, which is mainly possible through Fe chelates (Colombo et al., 2014). This form of Fe increases the accumulation of chlorophyll in plants, and because of its greater stability in alkaline soils, it has a higher efficiency in supplying Fe to trees (Homouda et al., 2015).

Proper management of fruit trees is essential to improve the quantity and quality of the product. The growing trend in the price of chemical fertilizers, the pollution of underground water, and the destruction of the soil structure due to their excessive use for high production have resulted in harmful economic results. Therefore, according to the global policy of optimizing the use of fertilizers and reducing the use of poisons, foliar spraying of nutrients appears to be a suitable method to reduce the use of chemical fertilizers and the resulting environmental risks. Therefore, this study was conducted to investigate the effect of foliar application of nitrogen, Fe, and P on the growth characteristics of 'Golden Delicious' apples.

## Materials and Methods

This experiment was carried out in 2019, as a factorial in a randomized complete block design in 3 replications (one tree per replication), on apple trees of the 'Golden Delicious' cultivar in a commercial orchard in Eqlid, Fars province, Iran (31.13° N, 52.55° E). The characteristics of orchard soil are given in Table 1. The study area, Eqlid in Fars province, has a semi-arid climate with average annual precipitation of approximately 345 mm. During the growing season (May–September), mean temperatures range from 22 °C in spring to 32 °C in midsummer.

In this study, the effects of foliar spraying of P, Fe, and urea from the time of leaf emergence (May) for 30 days once (three times) on the growth indicators were investigated. The experimental treatments were P (superphosphate) at three levels (0, 16 and 32 ppm), urea with 46% nitrogen at three levels (0, 1 and 2%) and Fe (Fe chelate) at three levels (0, 1.5 and 3 g·L<sup>-1</sup>) which was carried out with three replications and a total of 81 4-year-old 'Golden Delicious' apple trees grafted on the seedlings (5\*5 meters). At the end of the growing season (October), the number, length and diameter of fruits, leaf area, leaf chlorophyll, shoot length, height and concentrations of P, Fe and N elements in tree leaves were measured. In each tree, shoots were randomly selected in three different directions and the number of fruits was counted (Ferree and Warrington, 2003).

**Table 1.** Physicochemical characteristics of the experimental soil during the experiment season

Macro Parameters										
Clay (%)	Silt (%)	Sand (%)	pH	EC (mS·cm <sup>-1</sup> )	O.C (%)	SP (%)	TNV (%)	N (%)	K (ppm)	P (ppm)
12	34	54	7.5	0.47	1.2	41.7	25	0.1	350	11
Micro Parameters (ppm)										
B		Mn	Cu		Zn		Fe			
-		3.5	0.7		0.67		4.5			

### Fruit Length

To measure the length of the fruits, 10 fruits from each tree were placed along the length of each other. Then, using a digital caliper, their lengths were measured, and the length of the fruit was expressed as an average for each tree stem (Li et al., 2015).

### Fruit Diameter

To measure fruit diameter, 10 fruits from each tested tree were placed along the width of each other. Then, using a digital caliper, their width was measured and the fruit diameter was expressed as an average for each tree stem (Li et al., 2015).

### Shoot Length

Shoots were randomly selected in three different directions and their lengths were measured using a metal meter on a centimeter scale (Ferree and Warrington, 2003).

### Plant Height

To measure the height of the plant, at the time of choosing the trees to be tested, the height of each tree was measured using a meter from the crown to the tallest shoot, and at the end of the season, measurements were made again to determine the height of the plant (Ferree and Warrington, 2003).

### Leaf Chlorophyll

To measure leaf chlorophyll using a chlorophyll meter (model CCM-200/Opti-sciences), 10 leaves were selected from each tested tree and chlorophyll was expressed as an average (Arnon, 1967).

### Leaf Area

A Leaf Area Meter (WinArea\_UT\_11 model, Iran) was used to measure the leaf area. For this purpose, the number of 9 whole and healthy leaves from three directions (north, east and west) of each tree was randomly selected from the middle part of each shoot (Ferree and Warrington, 2003).

### Measuring the Concentration of Leaf Elements

#### *P Concentration*

First, to dry digest the leaves of the trees, the leaves of the plants, after cleaning with distilled water, were placed in an oven at a temperature of 75 °C for 48 h and then powdered using a grinder. 0.25 grams of each powdered sample was placed in

an oven at 550 °C for 3 h. To prepare the extract, 1.3 cc of 2N hydrochloric acid was added to the resulting ash, and after passing through a filter paper in a 100 cc flask, it was made up to volume using distilled water.

To measure the P concentration, a mixed solution (2.5 M sulfuric acid, ammonium molybdate, ascorbic acid, and antimony potassium tartrate) and a P standard were prepared. Standard solutions of zero, 25, 50, and 75 mg·L<sup>-1</sup> of the prepared standard were prepared in 50 cc flasks and before making up to volume with distilled water, 8 cc of the mixed solution was added to each flask. The plant extract (10 cc) and 8 cc of the mixed solution were added to a 50 cc flask, and the P concentration in the samples was calculated using a spectrophotometer (model BT600Plus, Canada) at a wavelength of 880 nm by drawing standard curves in percentage (Emami, 1996).

#### *Fe Concentration*

Digestion of plant samples to measure total Fe was performed using the acid digestion method (more digestion) with hydrochloric acid and concentrated nitric acid at a temperature of 300 °C, and the concentration of the element was determined using an atomic absorption device (Emami, 1996).

#### *N Concentration*

To measure nitrogen in tree leaves, after grinding and passing them through a 2 mm sieve, 50 g was separated from each sample. The samples were digested in special tubes using sulfuric acid, salicylic acid, hydrogen peroxide and selenium, and the nitrogen concentration was obtained by titration after distillation using a Kjeltex Auto 1030 Analyzer Techator device (Emami, 1996).

### Data Analysis

The data from this experiment were analyzed using SAS software, and the means were compared using Duncan's test.

## Results and Discussion

### Fruit Length

The results showed that the maximum lengths of the fruit were observed in treatments N<sub>2</sub>Fe<sub>2</sub>P<sub>0</sub> (0 ppm P, 3 g·L<sup>-1</sup> Fe and 2% urea fertilizer) (63.97 mm), N<sub>1</sub>Fe<sub>2</sub>P<sub>1</sub> (100 ppm P, 3 g·L<sup>-1</sup> Fe and 1% urea fertilizer) (65.91 mm) and N<sub>2</sub>Fe<sub>1</sub>P<sub>1</sub> (P 100 ppm, Fe 1.5 g·L<sup>-1</sup> and urea fertilizer 2%) (63.56 mm), which increased by 11.10,

10.99 and 10.39% respectively. However, there were no significant differences among the three treatments. The lowest fruit length was obtained in the control treatment (57.58 mm) (Table 2). The results showed that the maximum fruit length was observed in  $N_2Fe_2P_0$ ,  $N_1Fe_2P_1$ , and  $N_2Fe_1P_1$  treatments (Table 2). Beniwal et al. (1992) showed that foliar application of urea increased the length of grape pods. Dadrasnian et al. (2008) also stated that urea spraying did not affect the length of orange fruit. Zarei et al. (2017) found that foliar application of Fe chelate increased the length of pomegranate fruit compared to the control treatment. Fe increases photosynthesis and ultimately enhances fruit length (Mofakhami et al. 2009).

### Fruit Diameter

The maximum fruit diameter (73.07 mm) was obtained in the  $N_2Fe_2P_0$  treatment, which showed an increase of 13.78% compared with the control, and the lowest value was observed in the control treatment (64.22 mm) (Table 2). Based on these results, the maximum fruit diameter was obtained in the  $N_2Fe_2P_0$  treatment (Table 2). Quaggio et al. (2002) also stated that foliar application of N and P increased lemon diameter. According to Álvarez-Fernández et al. (2003), Fe deficiency led to a decrease in peach diameter. Babalar et al. (2015) reported that foliar application of Fe increased the size of apples. During reproductive growth, fruits absorb more photosynthetic material than other aerial organs do. Fe increases photosynthesis and ultimately effect fruit diameter (Mofakhami et al. 2009).

### Shoot Length

The maximum shoot length in  $N_2Fe_2P_1$  (100 ppm P, 3 g·L<sup>-1</sup> Fe, and 2% urea fertilizer) (94.6 cm),  $N_1Fe_0P_2$  (200 ppm P, 0 g·L<sup>-1</sup> Fe, and 1% urea fertilizer) (57 94.94 cm), and  $N_2Fe_1P_2$  (200 ppm P, 1.5 g·L<sup>-1</sup> Fe, and 2% urea fertilizer) (94.57 cm) was obtained, which resulted in an increase of 18.40 and 18.36%, respectively, compared to the control. However, no significant differences were observed among the three treatments. The lowest amount was obtained for the control treatment (79.90 cm) (Table 2). According to the results, the maximum shoot length was obtained in the  $N_2Fe_2P_1$ ,  $N_1Fe_0P_2$ , and  $N_2Fe_1P_2$  treatments (Table 2). The sufficiency of nutrients (nitrogen) and water affects the size and division of cells, thus increasing shoot length (Borrell and Hammer, 2000). Urea leads to an increase in the number and growth of shoots and fruits, and is effective in transferring leaf assimilates to them (Sedaqat Kish et al. 2012). Treeby et al. (1996) also stated that nitrogen foliar application increased the length of shoots in grapes. Sadaqat Kish et al. (2012) reported that nitrogen deficiency decreased the length of pomegranate shoots.

### Plant Height

Based on the results, the maximum plant height was observed in treatments N1 (40.96 cm) and N2 (39.63 cm), which caused an increase of 9.05 and 5.51 %, respectively, compared to the control, although there was a significant difference between these two treatments. The lowest height was obtained in the control treatment (zero percent urea fertilizer) (37.56 cm) (Table 3).

### Leaf Chlorophyll

The highest chlorophyll content was observed in the control treatments (56.83) and  $P_2$  (54.48). However, no significant differences were observed between the two treatments. The lowest amount was related to the  $P_1$  treatment (53.57), which caused a 74.5% reduction compared to the control (Table 3).

**Table 2.** Effect of treatments on fruit length, diameter and shoot length

Treatments	Fruit length (mm)	Fruit diameter (mm)	Shoot length (cm)
$N_0Fe_0P_0$ (control)	57.58 <sup>ef</sup>	64.22 <sup>g</sup>	79.9 <sup>i</sup>
$N_0Fe_0P_1$	61.8 <sup>abcde</sup>	71.17 <sup>abcd</sup>	84.53 <sup>fghi</sup>
$N_0Fe_0P_2$	60.77 <sup>abcdef</sup>	69.61 <sup>abcdef</sup>	81.2 <sup>i</sup>
$N_0Fe_1P_0$	58.29 <sup>cdef</sup>	68.12 <sup>bcdefg</sup>	81.7 <sup>hi</sup>
$N_0Fe_1P_1$	58.62 <sup>bcdef</sup>	67.85 <sup>bcdefg</sup>	82.57 <sup>ghi</sup>
$N_0Fe_1P_2$	61.82 <sup>abcde</sup>	69.68 <sup>abcdef</sup>	82.93 <sup>ghi</sup>
$N_0Fe_2P_0$	60.25 <sup>abcdef</sup>	68.64 <sup>abcdefg</sup>	82.1 <sup>hi</sup>
$N_0Fe_2P_1$	59.95 <sup>abcdef</sup>	68.44 <sup>abcdefg</sup>	81.23 <sup>i</sup>
$N_0Fe_2P_2$	57.31 <sup>ef</sup>	65.07 <sup>fg</sup>	82.2 <sup>hi</sup>
$N_1Fe_0P_0$	56.24 <sup>f</sup>	66.19 <sup>efg</sup>	93.8 <sup>ab</sup>
$N_1Fe_0P_1$	60.13 <sup>abcdef</sup>	68.94 <sup>abcdefg</sup>	93.47 <sup>ab</sup>
$N_1Fe_0P_2$	62.76 <sup>abc</sup>	70.72 <sup>abcde</sup>	94.57 <sup>a</sup>
$N_1Fe_1P_0$	57.05 <sup>f</sup>	65.37 <sup>fg</sup>	92.1 <sup>abcd</sup>
$N_1Fe_1P_1$	62.98 <sup>ab</sup>	70.98 <sup>abcde</sup>	92.57 <sup>abc</sup>
$N_1Fe_1P_2$	61.82 <sup>abcde</sup>	72.02 <sup>ab</sup>	87.8 <sup>cdef</sup>
$N_1Fe_2P_0$	60.39 <sup>abcdef</sup>	68.55 <sup>abcdefg</sup>	88.8 <sup>bcdef</sup>
$N_1Fe_2P_1$	63.91 <sup>a</sup>	72.05 <sup>ab</sup>	90.53 <sup>abcde</sup>
$N_1Fe_2P_2$	62.64 <sup>abcd</sup>	71.63 <sup>abc</sup>	91.4 <sup>abcde</sup>
$N_2Fe_0P_0$	58.68 <sup>bcdef</sup>	66.05 <sup>efg</sup>	86.53 <sup>efgh</sup>
$N_2Fe_0P_1$	58.86 <sup>bcdef</sup>	67.72 <sup>bcdefg</sup>	92.07 <sup>abcd</sup>
$N_2Fe_0P_2$	58.15 <sup>def</sup>	66.52 <sup>defg</sup>	87.2 <sup>defg</sup>
$N_2Fe_1P_0$	57.94 <sup>ef</sup>	67.62 <sup>bcdefg</sup>	91.33 <sup>abcde</sup>
$N_2Fe_1P_1$	63.56 <sup>a</sup>	69.52 <sup>abcdef</sup>	90.1 <sup>abcde</sup>
$N_2Fe_1P_2$	61.66 <sup>abcde</sup>	70.72 <sup>abcde</sup>	94.57 <sup>a</sup>
$N_2Fe_2P_0$	63.97 <sup>a</sup>	73.07 <sup>a</sup>	89.23 <sup>bcdef</sup>
$N_2Fe_2P_1$	58.37 <sup>bcdef</sup>	67.01 <sup>cdefg</sup>	94.6 <sup>a</sup>
$N_2Fe_2P_2$	59.94 <sup>abcdef</sup>	68.45 <sup>abcdefg</sup>	92.83 <sup>abc</sup>

Means followed by different letters in each column indicate significant difference at  $P < 0.05$  (Duncan test)

**Table 3.** Effect of treatments on plant height, and chlorophyll content

Treatments	Plant height (cm)
$N_{0(\text{control})}$	37.56 <sup>b</sup>
$N_1$	40.96 <sup>a</sup>
$N_2$	39.63 <sup>a</sup>
Treatments	Chlorophyll
$P_{0(\text{control})}$	56.83 <sup>a</sup>
$P_1$	53.57 <sup>b</sup>
$P_2$	54.48 <sup>ab</sup>

Means followed by different letters in each column indicate significant difference at  $P < 0.05$  (Duncan test)

According to the results, the application of P initially increased chlorophyll, but with increasing concentration, it did not show a significant difference compared with the control (Table 3). P is an essential nutrient for chlorophyll biosynthesis. In a study by Ling and Silberbush (2002), foliar application of P increased leaf chlorophyll in corn. Sawan et al. (2008) also stated that foliar application of P increased the chlorophyll content in cotton leaves. Chapagain and Wiesman (2004) showed that monopotassium phosphate foliar application led to an increase in the chlorophyll content in tomato leaves.

### Nitrogen Concentration

The highest concentration of nitrogen (5.79% by weight) was observed in the  $N_2Fe_2P_2$  treatment, which showed an increase of 50.78% compared with the control. The lowest amount was obtained for the control treatment (3.83% by weight) (Table 4). According to the results, the application of different levels of nitrogen increased the concentration of leaf nitrogen compared with the control (Table 4). Foliar application directly affects the concentration of leaf elements because in this way, elements are easily absorbed by leaves (Marschner, 2011). In a study by Ling and Silberbush (2002), foliar application of nitrogen and P increased the concentration of nitrogen in corn leaves. Khan et al. (2009) stated that two foliar applications of urea (before flowering and after flowering) significantly increased the leaf nitrogen content of quinoa trees compared with a single application before flowering or after fruiting and control trees. Karamnejad et al. (2018) reported that urea spraying led to an increase in leaf nitrogen concentration in Kino tangerines. Chermahini et al. (2011) stated that winter foliar application of urea, especially at the highest concentration, led to an increase in leaf surface nitrogen. Farzane and Golchin (2011) also reported that nitrogen application increased the percentage of nitrogen in tomato leaves. However Sedaghat Kish et al. (2013) stated that spraying urea led to the reduction of leaf nitrogen of pomegranates. Mohebi et al. (2016) found that the foliar application of Fe had no effect on apple leaf nitrogen concentration, but nitrogen application increased leaf nitrogen of apples cv. Fuji. In the study by Hamouda et al. (2015), with an increase in Fe concentration, the nitrogen concentration in wheat leaves first increased and then decreased. Monsef et al.

(2012) and Celik et al. (2010) found that a high dose of Fe caused a decrease in nitrogen concentration in corn leaves. Zarei et al. (2017) stated that the foliar application of Fe chelate alone and in combination with potassium phosphate did not affect the nitrogen concentration in pomegranate leaves. In the research of Farhan and Al-Dulaemi (2009), Fe foliar application increased nitrogen in wheat leaves.

### Phosphorus Concentration

The highest concentration was observed in  $N_0Fe_0P_2$  treatments (200 ppm P, 0 g·L<sup>-1</sup> Fe, and 0% urea fertilizer) (0.49%) and  $N_1Fe_2P_2$  (200 ppm P, 3 g·L<sup>-1</sup> Fe, and 1% urea fertilizer) (0.49%). The lowest amount was obtained in the control treatment (0.25%) (Table 4). The results showed that the highest P concentrations were obtained in the  $N_0Fe_0P_2$  and  $N_1Fe_2P_2$  treatments (Table 4). Foliar nutrition directly affects the concentration of leaf elements because in this way, elements are easily absorbed by leaves (Marschner, 2011). Ling and Silberbush (2002) reported that the foliar application of nitrogen and P increased the concentration of P in corn leaves. Karamnejad et al. (2018) showed that foliar application of urea increased leaf P concentration in Kino tangerine. Farhan and Al-Dulaemi (2011) found that the foliar application of Fe increased P in wheat leaves. In a study by Hamouda et al. (2015), with an increase in Fe concentration, the P concentration in wheat leaves first increased and then decreased. In the studies by Monsef et al. (2012) and Celik et al. (2010), a high dose of Fe decreased the concentration of P in corn leaves. Tagavi et al. (2005) stated that increasing Fe levels led to a decrease in P concentration in strawberry leaves.

### Iron Concentration

The highest total Fe concentration (0.152%) was observed in the  $N_2Fe_2P_2$  treatment (200 ppm P, 3 g·L<sup>-1</sup> Fe, and 2% urea fertilizer), which resulted in an increase of 42.07% compared to the control. The lowest amount was observed in the control treatment (0.107%) (Table 4). Based on these results, the application of different levels of Fe increased the concentration of total Fe in the leaves (Table 4). Foliar application directly affects the concentration of leaf elements because in this way, elements are easily absorbed by leaves (Marschner, 2011). This method of fertilization causes Fe to be deposited in the form of hydroxide on the surface of the leaf, and because the leaf lacks an acidification mechanism, foliar spraying with solutions with low pH causes mobility of the deposited compounds on the surface of the leaf and increases their absorption (Singh, 1970). Chapagain and Wiesman (2004) reported that foliar application of monopotassium phosphate increases the concentration of Fe in tomato leaves. Sadeghi et al. (2021) also stated that with an increase in the Fe concentration in Gala apples, the Fe concentration in the leaves increased. Erdal et al. (2004) showed that foliar application of Fe chelate increased Fe concentration in strawberry leaves. Zarei et al. (2017) reported that the foliar application of Fe chelate increased the Fe concentration in pomegranate leaves. Fernandez et al. (2009) stated that the foliar application of different Fe compounds increased the Fe concentration in peach leaves. Farhan and Al-Dulaemi (2009) found that the foliar application of Fe increased Fe in wheat leaves. In a study by Hamouda et al. (2015), with an increase in Fe concentration, the Fe concentration in wheat leaves first increased and then decreased. In the studies by Monsef et

al. (2012) and Celik et al. (2010), a high dose of Fe decreased the concentration of Fe in corn leaves. Mohebi et al. (2016) found that foliar Fe application had no effect on Fe concentration in apple leaves.

**Table 4.** Effect of treatments on N, P, and Fe concentrations

Treatments	N (%)	P (%)	Fe (%)
N <sub>0</sub> Fe <sub>0</sub> P <sub>0</sub> (control)	3.83 <sup>p</sup>	0.25 <sup>c</sup>	0.107 <sup>w</sup>
N <sub>0</sub> Fe <sub>0</sub> P <sub>1</sub>	4.06 <sup>o</sup>	0.4 <sup>ab</sup>	0.109 <sup>v</sup>
N <sub>0</sub> Fe <sub>0</sub> P <sub>2</sub>	4.06 <sup>o</sup>	0.49 <sup>a</sup>	0.109 <sup>v</sup>
N <sub>0</sub> Fe <sub>1</sub> P <sub>0</sub>	4.33 <sup>n</sup>	0.33 <sup>bc</sup>	0.126 <sup>p</sup>
N <sub>0</sub> Fe <sub>1</sub> P <sub>1</sub>	4.49 <sup>m</sup>	0.28 <sup>bc</sup>	0.127 <sup>o</sup>
N <sub>0</sub> Fe <sub>1</sub> P <sub>2</sub>	4.50 <sup>m</sup>	0.29 <sup>bc</sup>	0.128 <sup>m</sup>
N <sub>0</sub> Fe <sub>2</sub> P <sub>0</sub>	4.50 <sup>m</sup>	0.3 <sup>bc</sup>	0.139 <sup>i</sup>
N <sub>0</sub> Fe <sub>2</sub> P <sub>1</sub>	4.51 <sup>m</sup>	0.26 <sup>bc</sup>	0.141 <sup>h</sup>
N <sub>0</sub> Fe <sub>2</sub> P <sub>2</sub>	4.53 <sup>m</sup>	0.27 <sup>bc</sup>	0.142 <sup>g</sup>
N <sub>1</sub> Fe <sub>0</sub> P <sub>0</sub>	4.63 <sup>l</sup>	0.28 <sup>bc</sup>	0.112 <sup>u</sup>
N <sub>1</sub> Fe <sub>0</sub> P <sub>1</sub>	4.68 <sup>kl</sup>	0.31 <sup>bc</sup>	0.112 <sup>u</sup>
N <sub>1</sub> Fe <sub>0</sub> P <sub>2</sub>	4.71 <sup>jk</sup>	0.32 <sup>bc</sup>	0.113 <sup>t</sup>
N <sub>1</sub> Fe <sub>1</sub> P <sub>0</sub>	4.74 <sup>j</sup>	0.35 <sup>bc</sup>	0.132 <sup>m</sup>
N <sub>1</sub> Fe <sub>1</sub> P <sub>1</sub>	4.79 <sup>i</sup>	0.33 <sup>bc</sup>	0.132 <sup>m</sup>
N <sub>1</sub> Fe <sub>1</sub> P <sub>2</sub>	5.06 <sup>h</sup>	0.33 <sup>bc</sup>	0.133 <sup>l</sup>
N <sub>1</sub> Fe <sub>2</sub> P <sub>0</sub>	5.09 <sup>h</sup>	0.27 <sup>bc</sup>	0.144 <sup>f</sup>
N <sub>1</sub> Fe <sub>2</sub> P <sub>1</sub>	5.16 <sup>g</sup>	0.33 <sup>bc</sup>	0.147 <sup>e</sup>
N <sub>1</sub> Fe <sub>2</sub> P <sub>2</sub>	5.24 <sup>f</sup>	0.49 <sup>a</sup>	0.148 <sup>d</sup>
N <sub>2</sub> Fe <sub>0</sub> P <sub>0</sub>	5.66 <sup>e</sup>	0.25 <sup>c</sup>	0.118 <sup>s</sup>
N <sub>2</sub> Fe <sub>0</sub> P <sub>1</sub>	5.67 <sup>e</sup>	0.28 <sup>bc</sup>	0.120 <sup>r</sup>
N <sub>2</sub> Fe <sub>0</sub> P <sub>2</sub>	5.69 <sup>de</sup>	0.25 <sup>c</sup>	0.123 <sup>q</sup>
N <sub>2</sub> Fe <sub>1</sub> P <sub>0</sub>	5.71 <sup>cde</sup>	0.33 <sup>bc</sup>	0.133 <sup>l</sup>
N <sub>2</sub> Fe <sub>1</sub> P <sub>1</sub>	5.73 <sup>bcd</sup>	0.31 <sup>bc</sup>	0.135 <sup>k</sup>
N <sub>2</sub> Fe <sub>1</sub> P <sub>2</sub>	5.74 <sup>abcd</sup>	0.27 <sup>bc</sup>	0.136 <sup>j</sup>
N <sub>2</sub> Fe <sub>2</sub> P <sub>0</sub>	5.76 <sup>abc</sup>	0.27 <sup>bc</sup>	0.149 <sup>c</sup>
N <sub>2</sub> Fe <sub>2</sub> P <sub>1</sub>	5.78 <sup>ab</sup>	0.25 <sup>c</sup>	0.150 <sup>b</sup>
N <sub>2</sub> Fe <sub>2</sub> P <sub>2</sub>	5.79 <sup>a</sup>	0.35 <sup>bc</sup>	0.152 <sup>a</sup>

Means followed by different letters in each column indicate significant difference at  $P < 0.05$  (Duncan test)

## Conclusions

The results showed that foliar spraying of urea increased the concentration of nitrogen, Fe, and P elements in the leaves and also increased shoot length, leaf length, leaf circumference, and plant height. P foliar application increased the concentration of nitrogen, Fe and P elements in leaves, fruit length, fruit diameter and leaf chlorophyll. Foliar application of Fe increased the concentration of Fe and nitrogen elements in the leaves. The interaction of elements increased the concentration of nitrogen, Fe, and P elements in leaves, as well as fruit length, fruit diameter, and shoot length. According to the results, foliar spraying of the mentioned elements can be recommended as a complementary method to strengthen the growth of 'Golden Delicious' apple trees.

## CRedit Authorship Contribution Statement

**Fardin Mirzavandi:** Implementation, Conduction, Data collection. **Azam Jafari:** Study planning, Statistical analysis, Manuscript writing, English translation. **Mostafa Shirmardi:** Statistical analysis, Manuscript editing.

## Declaration of Competing Interest

The authors declare no known competing financial interests or personal relationships to influence the work reported in this manuscript.

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