The Effects of Different Fertilization Methods on the fruit quality of Lane Late Navel Oranges in Zigui

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Article Info

ISSN (online): 3049-0588
Volume: 02
Issue: 06
November - December 2025
Received: 05-09-2025
Accepted: 07-10-2025
Published: 04-11-2025
Page No: 11-15

Abstract
To compare the effects of different fertilization methods on the fruit quality of Zigui Lane Late navel oranges, especially on fruit greening and sugar loss, a field experiment was conducted in a Zigui Lane Late navel orange orchard in Guiya Village, Jiuanxi Town, Zigui County, Yichang City, Hubei Province. Five treatments were set up in the experiment, namely Treatment 1, Treatment 2, Treatment 3, Treatment 4, and Treatment 5, with 20 replicates for each treatment. The results showed that compared with Treatment 5, the single fruit weight, pulp weight, peel weight, transverse diameter, longitudinal diameter, and fruit shape index of the fruits treated with Treatment 1 did not increase significantly, but the coloring rate increased significantly by 343.50%, the peel hardness and pulp hardness decreased significantly by 13.69% and 13.66% respectively, the soluble solid content did not increase significantly, the titratable acid content did not increase significantly, the total sugar content increased significantly by 9.84%, the solid-acid ratio did not increase significantly, the sugar-acid ratio increased significantly by 9.41%, and the Vc content did not increase significantly. Compared with Treatment 5, the single fruit weight, pulp weight, peel weight, transverse diameter, and longitudinal diameter of the fruits treated with Treatment 2 increased significantly by 23.56%, 20.94%, 21.28%, 7.05%, and 9.59% respectively, the fruit shape index did not increase significantly, the coloring rate increased significantly by 339.79%, the peel hardness and pulp hardness decreased significantly by 15.47% and 6.20% respectively, the soluble solid content, titratable acid content, total sugar, and solid-acid ratio did not increase significantly, the sugar-acid ratio increased significantly by 22.35%, and the protein and Vc content did not increase significantly. Compared with Treatment 5, the single fruit weight, pulp weight, peel weight, transverse diameter, longitudinal diameter, and fruit shape index of the fruits treated with Treatment 3 did not increase significantly, the coloring rate increased significantly by 340.72%, the pulp hardness decreased significantly by 6.62%, the peel hardness, soluble solid content, titratable acid content, total sugar, protein, and Vc content did not increase significantly, the solid-acid ratio and sugar-acid ratio increased significantly by 20.35% and 28.24% respectively. Compared with Treatment 5, the single fruit weight, pulp weight, and transverse diameter of the fruits treated with Treatment 4 increased significantly by 19.30%, 20.00%, and 12.18% respectively, the peel weight and longitudinal diameter did not increase significantly, the fruit shape index decreased significantly by 7.14%, the coloring rate increased significantly by 519.18%, the peel hardness and pulp hardness decreased significantly by 21.30% and 12.93% respectively, the titratable acid content decreased significantly by 12.50%, the protein content did not differ significantly, and the soluble solid content, total sugar, solid-acid ratio, sugar-acid ratio, and Vc content increased significantly by 22.01%, 31.15%, 39.42%, 49.41%, and 20.14% respectively. Therefore, it can be concluded that the fertilization method of Treatment 4 has the most obvious effect on alleviating the greening phenomenon and sugar loss of Zigui Lane Late navel oranges.

DOI: https://doi.org/10.54660/GARJ.2025.2.6.11-15

Keywords: Lane Late Navel Orange, with Fruit Turning Green Again, Total Sugar Content

1. Introduction

Among all the various fruit trees planted across the country, the cultivation area and output of citrus fruits have been increasing year by year. In terms of both cultivation area and output, citrus fruits have surpassed apples and ranked first [1]. Citrus (Citrus) belongs to the Rutaceae family and the Citrus genus. It is a perennial evergreen small tree or shrub. Its varieties include oranges,

lemons, limes, tangerines, grapefruits, pomelos, and pomanders, and they have spread throughout tropical and subtropical regions around the world [1]. Luan Wan Qiu Orange is a plant of the Rutaceae family and the Citrus genus. It is a late-maturing variety of orange, also known as late-edge orange. It has a strong tree vigor, a relatively open tree shape, medium germination ability, strong branching ability, and three to four new shoots per year. The new shoots have no obvious short spines. Generally, the spring shoots and early autumn shoots are used as the fruiting mother branches. Its leaves are ovate, the leaf tip is blunt and round, the leaf color is dark green, its flower formation ability is strong, usually single flowers, a few flowers are umbellate inflorescences, the male sterility is present, and the fruit is elliptical, seedless, with a slightly convex top, smooth skin, orange-yellow color, yellowish center, and a single fruit weight of about 250 grams [1-2]. Luan Wan Qiu Orange is mainly planted in Jiangxi, Hunan, Guangxi, and Hubei provinces. Luan Wan Qiu Orange is suitable for subtropical monsoon climate, with abundant rainfall, sufficient sunlight, and thick soil layers, containing a large amount of minerals and trace elements. Luan Wan Qiu Orange is not tolerant to low temperatures and prefers warm and humid environments. The microclimate in the Qutai Reservoir area of Zigui County, Hubei Province, is very suitable for the growth of Luan Wan Qiu Orange [3]. However, Luan Wan Qiu Orange grown in Zigui County of Hubei Province often shows chlorosis. This chlorosis phenomenon is a natural physiological process during the growth cycle of Luan Wan Qiu Orange, manifested as the fruit skin changing from yellow to green in the later stage of ripening, which is a characteristic of the variety and to some extent affects the taste and quality of the fruit, and has a significant impact on the appearance of the fruit. Therefore, the chlorosis phenomenon of Luan Wan Qiu Orange seriously affects its commercial value. Compound fertilizers and microbial fertilizer have a certain alleviating effect on the chlorosis phenomenon of citrus fruit, and can reduce the loss of sugar during the chlorosis process [4]. Therefore, this study selected five different fertilization methods to fertilize Luan Wan fruit trees. By comparing the effects of different treatments on the chlorosis and quality of Zigui Luan Wan Qiu Orange fruits, it is expected to provide a scientific basis for choosing appropriate fertilization methods for Zigui Luan Wan Qiu Orange to effectively alleviate the problems of fruit chlorosis and sugar loss.

2. Materials and Methods

2.1. Experimental Materials

The experimental site is located in Guiya Village, Jiuyuanxi Town, Zigui County, Yichang City, Hubei Province, at an altitude of 436 meters. The tested variety is Zigui Lane Late Juangor orange, and the rootstock is Red Orange. All the experimental plants were grafted in March 2020 and have now entered the fruit-bearing period. The planting density is 80 plants per mu.

2.2 Experimental Design

Treatment involved 20 trees. Fertilization was applied starting in May 2024, while other fertilization and irrigation management as well as regular agricultural management remained unchanged. On November 29, 2024, fruit samples were collected from Luan Late Seed Mandarin once. For each treatment, 4 trees were randomly selected, and from each tree, one fruit was randomly picked from each of the 6 directions: east, west, south, north, up and down.

The five treatment methods of this experiment are shown in Table 1.

Table 1: Fertilizers applied under different treatments and related indicators

Treatment	Process mode
Treatment 1	In late October, 5 kilograms of organic microbial fertilizer per plant and 1 kilogram of compound fertilizer per plant (nitrogen: phosphorus: potassium = 20:10:15) were applied in the ditch. In late February, 0.5 kilograms of compound fertilizer (nitrogen: phosphorus: potassium = 15:10:20) was applied in the ditch. In mid-June, 1.5 kilograms of compound fertilizer (nitrogen: phosphorus: potassium = 20:5:20) was applied in the ditch.
Treatment 2	In late October, 5 kilograms of organic microbial fertilizer per plant and 1 kilogram of compound fertilizer per plant (nitrogen: phosphorus: potassium = 20:10:15) were applied to the ditch. In early February and mid-April, 80 grams of water-soluble fertilizer were respectively applied by irrigation (formula = 13N:3P:15K:8Ca:2Mg). In mid-June, 1.5 kilograms of compound fertilizer (nitrogen: phosphorus: potassium = 20:5:20) were applied to the ditch.
Treatment 3	In late October, 5 kilograms of organic microbial fertilizer per plant and 1.5 kilograms of compound fertilizer per plant (nitrogen:phosphorus:potassium = 20:10:15) were applied to the ditch. In early February, a sulfuric acid and lime mixture was sprayed before germination. In mid-March and mid-April, coloring trace element fertilizers were sprayed respectively. In late June, 1.5 kilograms of compound fertilizer (nitrogen:phosphorus:potassium = 20:5:20) were applied to the ditch.
Treatment 4	In late October, 5 kilograms of organic microbial fertilizer per plant and 1.5 kilograms of compound fertilizer per plant (nitrogen:phosphorus:potassium = 20:10:15) were applied to the ditch. In addition, monthly water-soluble fertilizer with a formula was irrigated in February, March, May, July and September (see Table 1). In March, May, July and September, poly-gamma-glutamic acid was sprayed every month.
Treatment 5	Regular fertilization involves applying organic microbial fertilizer of 2 kilograms per plant and compound fertilizer of 1 kilogram per plant (nitrogen: phosphorus: potassium = 15:15:15) in the furrows in late October; applying compound fertilizer of 1 kilogram per plant (nitrogen: phosphorus: potassium = 20:10:15) in mid-February; and applying compound fertilizer of 1.5 kilograms per plant (nitrogen: phosphorus: potassium = 20:5:20) in early June.

2.3. Measurement Methods

All the fruit test sheets measure indicators such as single fruit weight, flesh weight, peel weight, peel hardness, flesh hardness, transverse diameter and longitudinal diameter. After peeling the fruits, 10 mL of juice is squeezed out to analyze the edible rate, titratable acid, total soluble sugar, vitamin C content, and soluble solids content, etc. The single fruit weight and flesh weight are weighed using an electronic analytical balance, the transverse diameter and longitudinal diameter are measured with a vernier caliper, the peel hardness and flesh hardness are detected with a digital fruit hardness tester, the coloring rate is determined using Image J

software, the soluble solids content is determined using a refractometer, the total soluble sugar is detected using the acid hydrolysis copper reduction direct titration method, the titratable acid is determined using the NaOH neutralization titration method, and the vitamin C is determined using the ultraviolet spectrophotometry method [5-6].

2.4. Data Analysis

Data processing and analysis were conducted using Excel 2017 software. The data were subjected to variance analysis and significance test ($P < 0.05$) using SPSS Statistics 26.0 for comprehensive evaluation.

3. Results and Analysis

3.1. The effects of different fertilization methods on the fruit size and fruit shape index of Lengwanjiu orange in Zigui

As shown in Figure 1, treatments 1, 2, 3, and 4 can alleviate the chlorosis phenomenon of Lingwan Luandong tangerines to varying degrees. Compared with treatment 5, the single fruit weight, flesh weight, peel weight, diameter, length, and fruit shape index of the fruits treated with treatment 1 did not show significant increases. The single fruit weight, flesh weight, peel weight, diameter, and length of the fruits treated with treatment 2 increased significantly by 23.56%, 20.94%, 21.28%, 7.05%, and 9.59% respectively, while the fruit shape index did not show significant increase. The single fruit weight, flesh weight, and diameter of the fruits treated with treatment 3 did not show significant increases, and the fruit shape index decreased significantly by 7.14% (Table 2). Thus, the fruits treated with the compound fertilizer formula of treatment 2 and treatment 4 were larger in size and had thicker flesh. The fruits treated with the compound fertilizer formula of treatment 1 and treatment 3 showed no significant differences in fruit size and flesh thickness. The effect of the compound fertilizer formula of treatment 2 and treatment 4 was more obvious. It is worth noting that treatment 4 effectively alleviated the chlorosis phenomenon of Lingwan Luandong tangerines.

Fig 1: Effects of Different Fertilization Methods on the Fruit Shape and Coloration of Lane Late Navel Orange in Zigui

Table 2: The effects of different fertilization methods on the fruit characteristics of Lane Late Navel Orange

Treatment	Fruit Weight（g）	Pulp weight（g）	peel weight（g）	Fruit Diameter（mm）	Fruit Length（mm）	fruit shape index
Treatment 1	293.26 ± 28.13b	213.02 ± 15.17b	79.69 ± 6.58b	83.69 ± 7.18b	79.84 ± 6.05b	0.95 ± 0.06ab
Treatment 2	364.98 ± 31.01a	261.72 ± 21.21a	98.47 ± 8.44a	89.40 ± 7.06a	89.27 ± 6.78a	0.99 ± 0.08a
Treatment 3	304.69 ± 22.09b	226.64 ± 21.07b	77.39 ± 6.51b	82.56 ± 6.08b	78.50 ± 4.09b	0.95 ± 0.08ab
Treatment 4	352.41 ± 16.77a	259.68 ± 21.21a	82.15 ± 5.57b	91.08 ± 4.56a	82.95 ± 7.66ab	0.91 ± 0.05b
Treatment 5	295.39 ± 22.21b	216.40 ± 18.87b	81.19 ± 7.01b	83.51 ± 7.58b	81.46 ± 8.02ab	0.98 ± 0.07a

3.2. The effects of different fertilization methods on the external quality of Luonan Wenjiu orange fruits in Zigui

Compared with treatment 5, the coloring rates of treatments 1, 2, 3 and 4 increased by 343.50%, 339.70%, 340.72% and 519.18% respectively. The flesh hardness decreased by 13.66%, 6.20%, 6.62% and 12.93% respectively. There was no significant difference in the skin hardness among treatments 1, 2 and 3, while the skin hardness of treatment 4 decreased significantly by 21.31% (Table 3). Thus, the external quality of the fruits in treatment 4 was significantly improved, with the highest coloring rate and the least chlorosis phenomenon.

Table 3: The effects of different fertilization methods on the fruit quality traits of Lane Late Navel Orange

Treatment	Fruit Color Index（%）	Peel Firmness（N）	Flesh Firmness（N）	soluble solid（%）	Titratable Acidity（mg/100 mL）	total sugar（mg/100 mL）	Solid-to-acid ratio	sugar-acid ratio	protein（%）	Vc content（mg/100 g）
Treatment 1	70.25 ± 4.22b	22.32 ± 1.11ab	8.22 ± 0.45b	10.96 ± 0.96b	0.72 ± 0.04a	0.67 ± 0.02b	15.22 ± 1.06b	0.93 ± 0.04b	1.89 ± 0.11b	33.31 ± 2.78b
Treatment 2	68.44± 5.72b	21.86 ± 1.81ab	8.93 ± 0.74b	11.54± 1.01ab	0.68 ± 0.03ab	0.71 ± 0.05b	16.97 ± 1.12b	1.04 ± 0.07ab	1.99 ± 0.13ab	35.79 ± 3.12ab
Treatment 3	69.81 ± 5.21b	22.61 ± 1.87ab	8.89 ± 0.81b	12.01± 1.03ab	0.67 ± 0.04ab	0.73 ± 0.04b	17.92 ± 1.09ab	1.09 ± 0.05ab	2.07 ± 0.15ab	36.47 ± 2.56ab
Treatment 4	98.11± 4.27a	20.35 ± 1.54b	8.29 ± 0.79b	13.08± 1.02a	0.63 ± 0.02b	0.80 ± 0.04a	20.76 ± 1.88a	1.27 ± 0.11a	2.26 ± 0.19a	39.76 ± 3.02a
Treatment 5	15.84 ± 1.07c	25.86 ± 1.87a	9.52 ± 0.82a	10.72± 9.12b	0.72 ± 0.04a	0.61 ± 0.03b	14.89 ± 1.12b	0.85 ± 0.05c	2.03 ± 0.13ab	33.02 ± 2.45b

3.3. The effects of different fertilization methods on the internal quality of Luonan Wenjiu orange fruits in Zigui

Compared with treatment 5, the titratable acid content of the fruits treated with treatments 1, 2, and 3 did not show a significant decrease. The titratable acid content of treatment 4 decreased significantly by 12.50%. The total sugar content of treatments 1, 2, and 3 did not show a significant increase. The total sugar content of treatment 4 increased significantly by 23.75%. The solid-acid ratio of treatments 1 and 2 did not show a significant increase. The solid-acid ratios of treatments 3 and 4 increased significantly by 20.35% and 39.42% respectively. The sugar-acid ratios increased significantly by 9.41%, 22.35%, 28.24%, and 49.41% respectively (Table 3). Thus, the internal quality of the fruits from the compound fertilizers with treatments 1, 2, 3, and 4 was significantly improved. Among them, the compound fertilizer with treatment 4 had a more obvious effect.

3.4. The effects of different fertilization methods on the protein and vitamin C content of the fruits of Lengwanjiu orange in Zigui

Compared with treatment 5, the protein content of the fruits in treatments 1, 2, 3, and 4 did not show a significant increase. The vitamin C content of the fruits in treatments 1, 2, and 3 did not change significantly. However, the vitamin C content of the fruits in treatment 4 significantly increased by 20.14% (Table 3). Thus, applying the compound fertilizer formulated with treatment 4 can significantly increase the vitamin C content of the fruits.

4. Discussion and Conclusion

Compound fertilizers have the advantages of high nutrient content, adequate nutrition, and the ability to maximize the mutual promotion effect among elements [7]. Studies have shown that applying an appropriate amount of fertilizer can promote the growth of citrus trees, increase yield, and improve quality [8]. Microbial fertilizer is a new type of fertilizer that utilizes the physiological activity and metabolic functions of microorganisms to provide nutrients for crops, improve the soil, and prevent diseases and pests [9]. The main components of microbial fertilizer are one or more beneficial microbial strains, such as nitrogen-fixing bacteria, phosphorus-solubilizing bacteria, potassium-solubilizing bacteria, silicon-solubilizing bacteria, humic acid bacteria, etc. They can coexist with the crop roots in the soil and utilize the organic matter or inorganic salts in the soil to produce various active substances such as organic acids, plant hormones, and antibiotics, promoting the growth and development of crops and increasing the yield and quality of crops [9]. The results of this study are consistent with previous research, indicating that microbial fertilizer and compound fertilizer can significantly improve the internal and external quality of Luenan Qiujiang oranges, and effectively increase the commercial value of the fruits.

Effects of Different Fertilization Methods on the Fruit Size of Lane Late navels in Zigui.

It is worth noting that among the four formulations of compound fertilizers tested in this study, the formulation 4 had the most significant effects on increasing the fruit size, acid-sugar ratio, sugar-acid ratio, vitamin C content, and reducing the titratable acid content of the Zichui Lane Late Late Juicy Orange fruits. The effects of formulations 1, 2, and 3 were slightly less significant. Analyzing the reasons, it may be because the formulation 4 included a stable fertilizer (nitrogen: phosphorus: potassium = 20:10:15) in the microbial fertilizer. A stable fertilizer refers to a fertilizer produced during the production process that contains a urease inhibitor or a nitrate reduction inhibitor, or both inhibitors [10]. Currently, field trials have been conducted on crops such as rice, corn, and wheat, proving that the application of stable fertilizers can save time and labor, reduce production costs, increase yield and income, and improve economic benefits [10-13]. Studies by Xu [14], Kuai Jialin [15], and others have shown that the combination of stable fertilizers and microbial bacterial agents can significantly increase the yield and quality of lettuce. Xiang [16] also verified that the application of stable fertilizers and seaweed composite bacterial agents can increase the number of fruits per plant, the weight of individual fruits, and the yield per plant of 'New Holland' navel orange, and can also increase the soluble solids content, reduce the thickness of the fruit skin, improve the taste, and enhance the quality.

In this study, treatments 1, 2, 3 and 4 all significantly alleviated the phenomenon of premature ripening of Lane Late Mandarin fruits and inhibited the loss of fruit sugar content. Among them, treatment 4 was the most effective.

In conclusion, this experimental study shows that the application of the fourth formulation of the compound fertilizer has a significant effect on alleviating the chlorosis phenomenon of Luenan kumquat and reducing the loss of sugar content. The study indicates the relationship between the chlorosis phenomenon of citrus fruits and the accumulation of carotenoids in the fruit peel, and that ethylene has a significant regulatory effect on the accumulation of carotenoids [17]. Further research can investigate the changes in ethylene content in the fruits of Luenan kumquat during the later growth stage and the chlorosis period, and consider whether exogenous ethylene can be used for ripening or desaturation treatment to inhibit the chlorosis and sugar loss of Luenan kumquat fruits.

5. Funding: This experiment was supported by the 'Research on Techniques for Suppressing Fruit Chlorosis and Reducing Sugar Loss in Navel' project of the Science and Technology and Economy and Information Bureau of Zigui County.

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How to Cite This Article

Ma J, Chen Y, Xiang C, Hu Z, Yan Y, Tan J. The effects of different fertilization methods on the fruit quality of Lane Late navel oranges in Zigui. Glob Agric Res J. 2025;2(6):11-15. doi:10.54660/GARJ.2025.2.6.11-15

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