

Case Study

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Split Nitrogen Application Timing Enhances Fruit Set and Yield in Indeterminate Tomatoes

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Abstract Applying nitrogen fertilizer in stages is an effective way to enable unlimited-growth tomatoes to better absorb nutrients and increase yields. This study introduces the research situation in recent years on the impact of when and how many times nitrogen fertilizer is applied on the fruit setting quantity and total yield of tomatoes. It compares the effects of one-time fertilization only at the time of planting and staged fertilization, elaborates on how staged nitrogen application helps unlimited-growth tomatoes use nitrogen fertilizer more efficiently, how to extend the fruiting time, and how to make the fruits more easily obtain nutrients. The relationship between this fertilization method and the climate, the growth rhythm of tomatoes, as well as the coordinated growth between roots and branches and leaves was also discussed. This study aims to provide a scientific basis for improving fertilization methods, increasing yields, and making planting more environmentally friendly and sustainable.

Keywords Split nitrogen application; Indeterminate tomatoes; Fruit set; Nitrogen use efficiency; Reproductive duration

1 Introduction

Nitrogen is a very important nutrient element during the growth process of tomatoes. It directly affects whether the plants grow fast, whether the leaves are green, whether the fruits can grow large, and also affects the quality of tomatoes (Liang, 2024; Mao et al., 2024). If nitrogen is used appropriately, it can not only make tomatoes grow vigorously, but also increase the yield and make the fruits taste better (Wang et al., 2021; Luo et al., 2023; Wang et al., 2025). Studies have also found that the rational use of nitrogen fertilizer can increase the number of leaves, chlorophyll, fruit size of tomatoes, as well as nutritious components such as lycopene and vitamin C (Wang et al., 2021; Luo et al., 2023). However, using too much or too little nitrogen will lead to a decrease in yield, a deterioration in quality, and a waste of fertilizer. Therefore, when to apply nitrogen fertilizer and how to apply it most appropriately are the key steps in growing good tomatoes (Li et al., 2020; Luo et al., 2023; Wang et al., 2025).

Indeterminate tomatoes keep growing, flowering and fruiting. Their growth period is relatively long, and they have higher requirements for nutrients when growing leaves and fruiting. Tomatoes have different nitrogen requirements at different growth stages. During the seedling stage and the early flowering period, it mainly relies on nitrogen in the soil. But when the fruits start to grow, nitrogen supplementation outside is needed (Hernández et al., 2020; Wang et al., 2025). So, if fertilizer is applied only once, it may not meet the demand for the entire season. Reasonable arrangement of when to apply nitrogen fertilizer can help tomatoes bear more fruits and grow better (Wabela, 2018; Ayankojo and Morgan, 2021; Wang et al., 2025).

This study discussed the extent to which several applications of nitrogen fertilizer had an impact on the fruit setting rate and yield of indeterminate tomatoes. By comparing several different fertilization schemes, the best time and proportion were identified, and how these practices affected the growth and fruiting of indeterminate tomatoes were analyzed. This study hopes to provide practical experience for growing this type of tomato and also help make better use of nitrogen fertilizer resources.

2 Nitrogen Uptake and Utilization in Tomato Plants

2.1 Mechanisms of nitrogen absorption and transport

Tomatoes mainly absorb nitrogen from the soil through their root systems, mainly ammonium nitrogen and nitrate nitrogen. Whether the root system can efficiently absorb this nitrogen is related to the microorganisms around the roots, the amount of organic matter in the soil, and the type of nitrogen. Studies have found that if some beneficial bacteria, such as *Bacillus pumilus*, are added to the soil, it can help tomatoes absorb nitrogen better, and at the same time, it can also make the nitrogen in the soil transform faster and have a better absorption effect (Masood et al., 2020). In addition, soil additives such as biochar and humic acid can also improve soil quality, make roots more active and enhance their nitrogen absorption capacity (Qin et al., 2023; Zhang et al., 2023). The nitrogen absorbed by the plant is transported to parts such as leaves, stems and fruits through the plant's conducting tissues (such as xylem and phloem) to meet the needs at different stages (Liu et al., 2020; Wang et al., 2025).

2.2 Role of nitrogen in vegetative and reproductive development

Nitrogen is of great significance to tomatoes. It affects the size of leaves, the intensity of photosynthesis, the amount of dry matter accumulated by the plants, and ultimately determines the yield. If nitrogen is supplied just right, it will make the leaves grow faster, be greener in color and have a higher photosynthetic efficiency (Zhang et al., 2021a; Zhang et al., 2021b). When tomatoes start to flower and bear fruit, the demand for nitrogen will increase further. Sufficient nitrogen is conducive to more flowering and fruiting, and the yield will also increase accordingly (Wang et al., 2024a; Wang et al., 2025). However, if too much nitrogen is applied, not only will the output not continue to increase, but also the utilization rate of nitrogen will decrease, causing waste and even polluting the environment (Liu et al., 2020; Wang et al., 2025). Applying nitrogen fertilizer in stages can better meet the needs of tomatoes at each stage, improve the utilization rate of nitrogen, and make the yield more stable (Wang et al., 2025).

2.3 Nitrogen metabolism specific to indeterminate growth types

Indeterminate tomatoes keep growing, flowering and bearing fruit. Their demand for nitrogen is phased and dynamically changing. During the seedling stage, it mainly relies on the original nitrogen in the soil. When it comes to flowering and fruit expansion, additional nitrogen needs to be supplemented externally (Wang et al., 2025). If there is not enough nitrogen at this time, tomatoes will recycle the nitrogen in their bodies through the mechanism of "autophagy", for example, through the ATg6-dependent pathway to improve their adaptability to a low-nitrogen environment (Figure 1) (Cao et al., 2022). Some research has also found that grafting rootstocks with high nitrogen efficiency can help tomatoes absorb nitrogen better, increase the activity of key enzymes, make better use of nitrogen, and improve yield and quality accordingly (Zhang et al., 2021a; Zhang et al., 2021b). In addition, the forms of nitrogen (such as the ratio of ammonium to nitrate) and the environmental conditions around the roots, such as the distribution of soil salinity, also affect the effect of nitrogen absorption and utilization in tomatoes (Wang et al., 2024a; Wang et al., 2024b).

3 Limitations of Single-Dose Nitrogen Application

3.1 Risk of nitrogen loss: leaching and volatilization

If nitrogen fertilizer is applied all at once, it is very likely to cause waste of fertilizer. Especially in cases of heavy rainfall or frequent irrigation, nitrogen will be washed by water to the deep soil, and the roots cannot absorb it (Nie et al., 2021; Sun et al., 2023). In addition, nitrogen may also volatilize and escape into the air, not only reducing the fertilizer efficiency but also polluting the environment.

3.2 Nutrient imbalance and excess vegetative growth

Applying a large amount of nitrogen at one time may also cause tomatoes to grow too fast, with only leaves, no flowers or no fruits (Nie et al., 2021; Wang et al., 2025). In fact, tomatoes do not have a high demand for nitrogen during the seedling stage. If too much nitrogen is applied at this time, it will not only be ineffective but also easily cause the plants to grow excessively, affecting the subsequent fruiting and yield (Zhou et al., 2020; Wang et al., 2025).

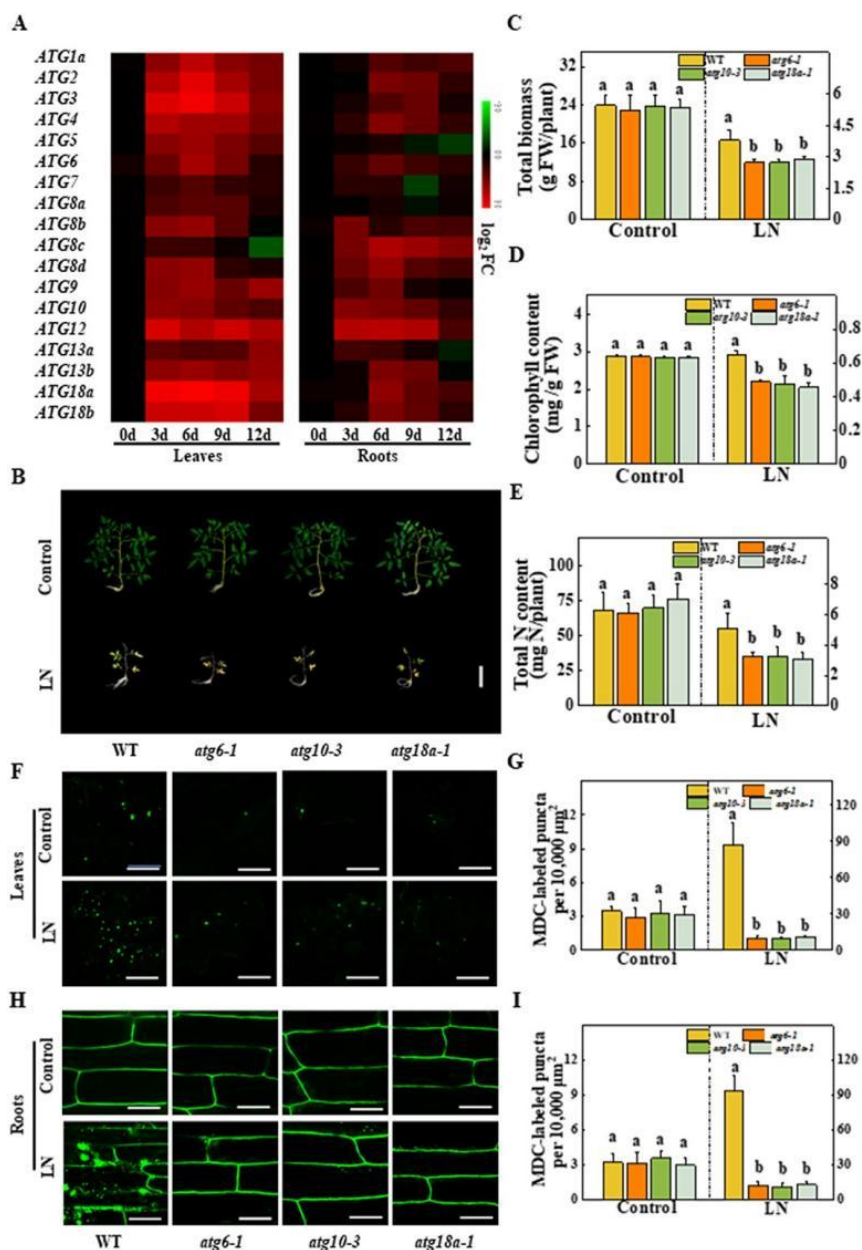


Figure 1 Role of autophagy in the response to LN stress in tomato (Adopted from Cao et al., 2022)

3.3 Economic and environmental consequences

Another problem with one-time fertilization is the low utilization rate, that is, the fertilizer is used but not absorbed, wasting money in vain (Du et al., 2020; Nie et al., 2021). If nitrogen flows into water, it will also deteriorate the water quality, cause eutrophication of water bodies and bring troubles to the environment (Du et al., 2020; Sun et al., 2023). Therefore, compared with one-time fertilization, applying nitrogen fertilizer in several installments can better improve the utilization rate, and also reduce costs and environmental impacts (Wabela, 2018; Nie et al., 2021; Wang et al., 2025).

4 Principles and Strategies of Split Nitrogen Application

4.1 Definition and general concepts of split application

Applying nitrogen fertilizer in installments means applying it several times at different growth stages of tomatoes instead of applying it all at once. This is done to enable tomatoes to absorb nitrogen exactly when they need it, improve the utilization efficiency, and also reduce waste and pollution (Wabela, 2018; Ayankojo and Morgan, 2021; Wang et al., 2025). Studies have found that this method can increase the yield and quality of tomatoes more than single fertilization (Wabela, 2018).

4.2 Timing strategies: pre-planting, flowering, fruit set, and ripening

The key to applying nitrogen fertilizer in different parts is to choose the right time for fertilization. Apply a portion before planting to help the seedlings take root and grow leaves during the seedling stage (Ayankojo and Morgan, 2021). When flowering, not much nitrogen is used. The nitrogen in the soil is sufficient. Excessive application is prone to waste (Wang et al., 2025). When tomatoes start to bear fruit, their demand for nitrogen increases, and appropriate topdressing helps the fruit grow (Wabela, 2018; Wang et al., 2025). When the fruits are nearly ripe, a little nitrogen can also be supplemented to maintain the quality, but not too much, otherwise it will affect the fertilizer efficiency (Luo et al., 2023; Wang et al., 2025). Studies have shown that applying nitrogen fertilizer in a ratio of “50% before sowing + 50% during growth” or “25% before sowing + 75% during growth” can yield more fruits and have better quality (Wabela, 2018; Ayankojo and Morgan, 2021).

4.3 Methods of application: fertigation, foliar sprays, side-dressing

There are many ways to apply nitrogen fertilizer separately. For example, irrigation fertilization involves dissolving fertilizers in water and applying them together. It is often used in drip irrigation systems, which can supply fertilizers evenly and is particularly economical (Du et al., 2020; Liu et al., 2020; Bello et al., 2024). Foliar fertilization involves spraying fertilizer onto leaves, which is suitable for rapid nitrogen supplementation during critical periods and can enhance the resistance and fruit quality of plants (Luo et al., 2023). There is also furrow topdressing, which involves digging small furrows beside the seedlings for fertilization. It is often used in conjunction with watering and is suitable for field cultivation (Wabela, 2018; Ayankojo and Morgan, 2021).

5 Impact of Application Timing on Tomatoes Physiology

5.1 Effects on root-to-shoot ratio and biomass allocation

Applying nitrogen fertilizer in multiple installments can make the roots and above-ground parts of tomatoes grow more reasonably and also increase the total weight of the plants. Studies have found that applying a portion of the fertilizer before planting and supplementing it later can help tomatoes grow faster and have deeper root systems in the early stage. Especially under the condition of reasonable irrigation, this method enables more roots to grow into the deep soil, which is conducive to the absorption of water and nutrients, and finally increases the yield (Ayankojo and Morgan, 2021; Nie et al., 2022). Moreover, a reasonable arrangement of the dosage and timing of nitrogen fertilizer can also enable roots and stems to grow better and accumulate more dry matter (Nie et al., 2022).

5.2 Influence on flower development and fruit set

Applying nitrogen in batches can also help flowers develop well and increase the fruit setting rate. Studies have pointed out that supplementing nitrogen fertilizer during the flowering and fruiting periods of tomatoes can enable normal flower development and smooth pollination, thereby increasing the number of fruits (Wabela, 2018; Wang et al., 2025). Adding nitrogen fertilizer in the middle and later stages is also conducive to fruit growth, reduces flower and fruit drop, and increases the yield per plant (Wabela, 2018; Wang et al., 2025).

5.3 Delaying senescence and extending harvest duration

In addition to promoting growth, applying nitrogen fertilizer in installments can also slow down the aging of leaves and prolong the harvest time. Timely nitrogen supplementation can maintain strong photosynthesis and higher chlorophyll content, keep the leaf function for a longer time, and also prolong the fruit development and harvest time (Nie et al., 2021; Nie et al., 2022). In addition, reasonable nitrogen fertilizer management can also enable tomatoes to absorb nitrogen more efficiently and grow more vigorously throughout the growth period, which is conducive to maintaining a good yield and quality all the time (Du et al., 2020; Wang et al., 2025).

6 Yield and Quality Benefits of Optimized Nitrogen Scheduling

6.1 Total and marketable yield improvements

Applying nitrogen fertilizer in batches can significantly increase the total yield of tomatoes and the number of commercial fruits. Research has found that applying nitrogen fertilizer in two installments, such as once during transplanting and again during growth, with half each time, can achieve the highest yield, reaching 39.33 tons per hectare, which is much better than applying it all at once (Wabela, 2018). Among different fertilization levels,

controlling nitrogen fertilizer between 125 and 200 kilograms per hectare leads to more commercial fruits, higher benefits, and can also improve the utilization rate of nitrogen fertilizer (Ronga et al., 2020; Shewangizaw et al., 2024). If combined with reasonable irrigation, the yield and water use efficiency can continue to increase (Li et al., 2020; Bello et al., 2024; Shewangizaw et al., 2024).

6.2 Fruit size, color uniformity, and shelf life

If the fertilization method is well arranged, it can not only increase the yield but also make the tomatoes grow more beautifully. Appropriate and divided fertilization can make fruits larger in size and grow more evenly (Wang et al., 2021). When the supply of nitrogen is sufficient, tomatoes have brighter colors and can be stored for a longer time. At this time, the fruits have a high sugar content and a low acidity, and are more advantageous in transportation and preservation (Li et al., 2020; Wang et al., 2021; Luo et al., 2023; Bello et al., 2024). Moreover, if nitrogen fertilizer is used just right, tomatoes will have a stronger tolerance to high temperatures, and their appearance and quality can be better maintained (Luo et al., 2023).

6.3 Nutritional quality enhancements

Applying nitrogen fertilizer in batches and in appropriate amounts can also enhance the nutritional value of tomatoes. Studies show that after scientific management of nitrogen fertilizer, the levels of vitamin C, sugar and lycopene in fruits will all increase (Li et al., 2020; Wang et al., 2021; Fan et al., 2022; Luo et al., 2023). If nitrogen fertilizer is appropriately reduced or less applied at certain stages, not only will the yield not decrease, but instead there will be more vitamin C and phenolic components in the fruits, making them more nutritious to eat (Hernández et al., 2020). In addition, when nitrogen fertilizer is applied appropriately, tomatoes can absorb more nutritional minerals such as protein, potassium and phosphorus, further improving the overall nutritional quality of the fruit (Ronga et al., 2020; Fan et al., 2023).

7 Interaction with Agronomic and Environmental Factors

7.1 Relationship with irrigation schedules

The application of nitrogen in batches is closely related to the irrigation method and has a significant impact on both the fruit setting rate and yield of tomatoes. Under the planting methods of drip irrigation and furrow irrigation, using nitrogen fertilizer separately and multiple times can make tomatoes grow better and use less water. For example, in arid areas, if only half of the water is irrigated (such as using only 50% of the normal water volume), along with an appropriate amount of nitrogen fertilizer, not only can tomatoes grow well, have more fruits, and have better quality, but water can also be used more efficiently (Li et al., 2020; Fan et al., 2022; Bello et al., 2024). Under furrow irrigation conditions, if nitrogen fertilizer is divided into half for transplanting and half for the middle and late stages, the yield will be higher than applying it all at once (Wabela, 2018). In addition, adjusting the application time of nitrogen fertilizer and combining it with water-saving irrigation methods (such as phased water supply) can also ensure the yield while saving water (Ayankojo and Morgan, 2021).

7.2 Effects under organic and integrated nutrient management systems

In organic farming or integrated nutrient management, applying nitrogen in stages also has obvious benefits. Research has found that during the seedling stage of tomatoes, less fertilizer is used. When they flower, they rely on the original nitrogen in the soil. It is not until the fruiting stage that more fertilizer is needed. If fertilizers are used reasonably according to each growth stage, not only can the yield be increased, but also the waste of fertilizers or nutrient imbalance can be avoided (Wang et al., 2025). In addition, some studies using foliar spraying of organic nitrogen (such as arginine) have also found that it can enable tomatoes to accumulate more nitrogen, enhance photosynthesis in leaves, and improve fruit quality (Wang et al., 2021). These results indicate that in organic farming, it is very important to apply fertilizers reasonably in stages.

7.3 Influence of soil type and climatic conditions

Soil type and weather conditions can also affect the effect of phased nitrogen application. The effects of applying nitrogen in batches vary in different soils such as sandy soil and loam. Like in sandy soil, the fruit becomes larger more obviously in the later stage. But in loam soil, this effect is not very prominent. In different seasons, whether it is drought or humidity, the combination mode of water and fertilizer will also change, thereby affecting the yield

and quality of tomatoes (Fan et al., 2022; Bello et al., 2024; Fidler et al., 2025). For instance, when the temperature is high or evaporation is fast, nitrogen fertilizer may be more prone to loss or have a lower utilization rate. Therefore, fertilization plans should be determined based on local weather and soil conditions in different places (Li et al., 2020; Ayankojo and Morgan, 2021).

8 Case Study: Greenhouse Trials on Split Nitrogen in Indeterminate Tomatoes

8.1 Trial design and nitrogen allocation schedules

In greenhouse experiments, a randomized block design is usually adopted, and several different time schedules for nitrogen fertilizer application are set. The more common practices include applying all nitrogen fertilizer at once during transplanting and using the nitrogen fertilizer in two separate applications. For instance, use half of it when transplanting and the other half after the plant has grown to a certain stage. Apply 25% of the nitrogen fertilizer at the time of transplanting, and the remaining 75% should be applied when the plants enter their growth peak period. In addition, a control group without nitrogen fertilizer application was also set up (Wabela, 2018; Wang et al., 2025).

Some experiments also incorporated different irrigation methods (such as total irrigation, water-saving irrigation or controlled irrigation) to observe the effects of the combination of irrigation methods and nitrogen fertilizers (Zhou et al., 2020; Ayankojo and Morgan, 2021; Sun et al., 2023). In the experiment, the total dosage of nitrogen fertilizer was generally determined based on soil testing or recommended values, and was reasonably allocated according to the growth stage, with a focus on the fertilizer requirements at the seedling stage, flowering stage and fruiting stage (Zhou et al., 2020; Wang et al., 2025).

8.2 Measured outcomes: fruit set, yield, and nitrogen use efficiency

The test results revealed that applying nitrogen in batches could significantly increase the fruit setting rate and total yield of tomatoes. The treatment of using half of the nitrogen fertilizer during transplanting and the other half in the later stage achieved the highest yield, reaching 39.33 tons per hectare. The combined yield of 25%+75% was 33 tons per hectare, which was also better than one-time fertilization (Wabela, 2018). In a greenhouse environment, choosing an appropriate total amount of nitrogen fertilizer (such as N60-N80, corresponding to 93-128 kilograms of nitrogen per hectare) not only leads to high yields but also enables more efficient utilization of nitrogen fertilizer. If too much is applied, it will instead cause waste (Wang et al., 2025).

Because tomatoes use less fertilizer during the seedling stage, they mainly rely on nitrogen in the soil during the flowering stage, and by the fruiting stage, they are even more dependent on nitrogen in the fertilizer. Therefore, applying nitrogen fertilizer in stages is more in line with the growth requirements of tomatoes (Zhou et al., 2020; Sun et al., 2023; Wang et al., 2025). If combined with appropriate irrigation methods at the same time, such as moderate and less watering, the utilization rates of fertilizers and water can be further improved, making the root system more developed and the fruits better (Zhou et al., 2020; Ayankojo and Morgan, 2021; Sun et al., 2023).

8.3 Economic analysis and farmer adoption potential

In addition to increasing the yield, applying nitrogen in several installments can also make nitrogen fertilizer less likely to be wasted, have higher fertilizer efficiency, and reduce the impact on the environment (Du et al., 2020; Wang et al., 2025). Economic analysis reveals that if the amount of nitrogen fertilizer is appropriately reduced and the fertilization time is properly arranged, not only is the output not reduced, but the input-output ratio is also higher and the profit is better (Du et al., 2020; Fan et al., 2022). For instance, one approach is to irrigate the entire process with one-third of the water volume, combined with two-thirds of the recommended amount of nitrogen fertilizer. The result is excellent in terms of yield, fruit quality and economic benefits, and is highly suitable for promotion to farmers (Fan et al., 2022). In addition, the operation of stepwise nitrogen application is not complicated and can be matched with the current irrigation system. It is easy for farmers to master and use (Du et al., 2020; Fan et al., 2022). Overall, this phased nitrogen application management approach can help the unlimited-growth tomatoes in greenhouses achieve the goals of high yield, high efficiency and environmental protection.

9 Environmental and Sustainability Perspectives

9.1 Reduction in nitrogen footprint and greenhouse gas emissions

Applying nitrogen fertilizer in multiple installments can not only increase the yield of tomatoes but also reduce the problem of excessive fertilizer use. In this way, nitrogen fertilizer will not accumulate too much in the soil, and the risk of nitrogen loss and greenhouse gas emissions can also be reduced. Studies have found that if tomatoes are fertilized in stages according to their needs, not only will the fertilizer utilization efficiency be higher, but the environmental pressure will also be reduced (Du et al., 2020; Li et al., 2022). In addition, some new planting methods, such as “Integrated Crop and Nitrogen Management” (ICNM) or oxygen-infused irrigation techniques, can also reduce the amount of nitrogen fertilizer used without affecting the yield, helping to lower the nitrogen footprint of agriculture (Du et al., 2020; Li et al., 2022).

9.2 Contribution to sustainable fertilizer management

Applying nitrogen in stages can also enable plants to better absorb the fertilizer, making it more fully utilized and thus less likely to be wasted. Many experiments have found that if nitrogen is applied according to the needs of crops at different growth stages and combined with appropriate irrigation methods, not only will the yield and fruit quality be improved, but also the utilization efficiency of nitrogen fertilizer can be enhanced (Wabela, 2018; Du et al., 2020; Li et al., 2020; Fan et al., 2022; Wang et al., 2025). This approach also enhances “productivity of nitrogen” (PFPn) and “water use efficiency” (WUE), enabling both water and fertilizer to be used more efficiently. In addition, applying nitrogen in multiple stages can also make the roots of tomatoes grow better. When the root system is stronger, the ability to absorb nutrients is also stronger, and the overall nitrogen utilization rate is naturally higher (Li et al., 2022).

9.3 Policies and guidelines for climate-smart nitrogen use

In order to make agriculture more sustainable, it is very important to formulate reasonable nitrogen fertilizer management policies. The research suggests that the amount of nitrogen fertilizer should be adjusted according to the growth stage of the crops. For instance, the demand for nitrogen is not high during the seedling stage and the flowering stage, so too much should not be applied at these times. When the fruits start to expand, a little more can be applied appropriately. This can not only ensure the yield but also protect the environment (Hernández et al., 2020; Wang et al., 2025). In addition, it is also very helpful to promote some advanced methods, such as “integrated crop-nitrogen management”, precise irrigation and staged fertilization, etc. These technologies can help farmers use fertilizers more scientifically. They not only reduce pollution but also enhance agriculture’s ability to cope with climate change, making planting more stable and long-lasting (Du et al., 2020; Li et al., 2022).

10 Concluding Remarks

Applying nitrogen fertilizer separately at different growth stages can significantly increase the fruit setting rate and yield of indeterminate tomatoes. Many studies have found that applying part of the nitrogen fertilizer during the transplanting period and part for later growth (such as “50%+50%” or “25%+75%”) usually yields better than applying it all at once. This way, not only are there more fruits, but their quality is also better. For instance, the content of soluble solids and vitamin C is higher, and the utilization of nitrogen fertilizer and water is also more efficient. Moreover, tomatoes use less nitrogen during the seedling stage. During the flowering period, they mainly rely on nitrogen in the soil. It is not until the fruit expands that they truly need to supplement fertilizers. So it is very important to arrange fertilization according to the growth stage of tomatoes.

It is recommended that farmers adopt the method of phased nitrogen application, especially the combination mode of “transplanting period + growth period”, which can better increase the yield and fertilizer efficiency. If water is tight, you can also combine it with moderate water-saving irrigation, such as controlling the watering time or frequency. This not only saves water but also improves the quality of the fruit. When promoting this technology, it is necessary to strengthen the training for farmers and teach them how to fertilize scientifically according to the growth of tomatoes to avoid waste and harm to the environment. In addition, precise irrigation and fertilization methods such as drip irrigation and sub-film drip irrigation are also recommended to be used in combination, which can make fertilizer and water management more meticulous.

However, there is currently no one-size-fits-all fertilization plan. Different soils, climates and tomato varieties may require different fertilization times and ratios. In addition, how to optimize the management of nitrogen fertilizer and water simultaneously remains to be further studied. In the future, we can pay attention to new technologies such as AI intelligent fertilization and soil nitrogen sensors. They may help us achieve real-time regulation of nitrogen fertilizer, making fertilization more accurate and environmentally friendly. Future research can also give more consideration to how these techniques can be combined and the long-term effects of staged fertilization on tomato quality and ecology.

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Conflict of Interest Disclosure

The authors affirm that this research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

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