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Optimizing Nitrogen Management for Sustainable Tomato Production in North Florida[1]

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Introduction

In north Florida, the common practice of growing fresh market tomatoes in sandy soils presents significant challenges, particularly in maintaining adequate water and nutrient levels within the rootzone. While the recommended nitrogen (N) fertilization rate for tomatoes is 200 lb/ac, many commercial growers likely apply higher rates to prevent any potential yield losses. However, over-application can lead to environmental issues, such as N leaching into groundwater and N runoff into surface water bodies. Vegetable production systems under various production conditions (e.g., crop type, soil type, organic matter content, cultivation practices, and climate) have shown low fertilizer N use efficiency (NUE) ranging from 30% to 50% (Mosier et al. 2004; Jalpa and Mylavarapu 2021; Jalpa et al. 2024), highlighting the need for more targeted N management strategies. Best Management Practices (BMPs) have been specifically designed for commercial vegetable production to address these challenges. These practices aim to optimize N management, sustain yields, and minimize losses. Vegetable production fields employ raised-bed plasticulture systems combined with drip irrigation, which efficiently delivers water and nutrients in controlled, frequent applications as part of standard BMPs (Jalpa and Mylavarapu 2023).

Research on improving NUE in tomato cultivation has further extended beyond traditional BMPs to include the use of polymer-coated, controlled-release fertilizers (CRFs) (see EDIS publication HS1255, "Controlled-Release and Slow-Release Fertilizers as Nutrient Management Tools") as an alternative to conventional fertilizer formulations. The use of CRFs is now part of standard BMPs in the state (FDACS 2015). These CRFs are designed to release N gradually throughout the crop growth cycle. A controlled release not only matches the nutrient needs of the plants more closely but also minimizes the need for frequent fertilizer applications, thereby reducing labor and the risk of environmental contamination from N runoff or leaching. While CRFs offer significant advantages in terms of plant health and environmental protection, their higher cost—often higher than conventional fertilizers—may discourage some growers from using them. Recognizing this barrier, any available incentives, such as market subsidies and credits provided by state or federal agencies designed to offset initial costs, must be explored. Such financial aids typically aim to encourage grower adoption of BMPs such as CRFs and to help growers realize the long-term benefits for crops and the ecosystem. This publication is intended for commercial crop producers, crop consultants, crop advisers, state agencies, researchers, Extension specialists and agents, graduate students, and the general public who are interested in improved N management for horticultural and environmental sustainability.

Nitrogen Fertilizer Study

A four-season study, conducted during both fall and spring (Figure 1), evaluated the effectiveness of polymer-coated CRFs compared to the conventional fertigation method (conventional system) in the sandy soils of north Florida to help validate the CRF as a BMP. The study focused on optimizing NUE by applying the "4Rs" of fertilization strategy: right rate, right source, right timing, and right placement (Hochmuth et al. 2014). These principles not only ensure that N is applied in the most efficient manner possible but also aim to meet only the specific N requirements of the crop, which is crucial in sandy soils with higher potential for nutrient losses (Hochmuth and Hanlon 2016). The conventional and alternate N management programs are detailed in Table 1 and Figure 2. Both fertilizer programs adhere to the UF/IFAS and state agency guidelines for water and fertilizer BMPs. For more detailed guidance on vegetable production BMPs, refer to the latest edition of the *Vegetable Production Handbook of Florida* and the Florida Department of Agriculture and Consumer Services (FDACS) vegetable and agronomic crops BMP manual.

Figure 1. Spring (left) and fall (right) tomato production systems on sandy soils in Citra, Florida. Seasonal adaptations include the use of black or white plastic mulch.
Credit: Laura Jalpa, formerly UF/IFAS

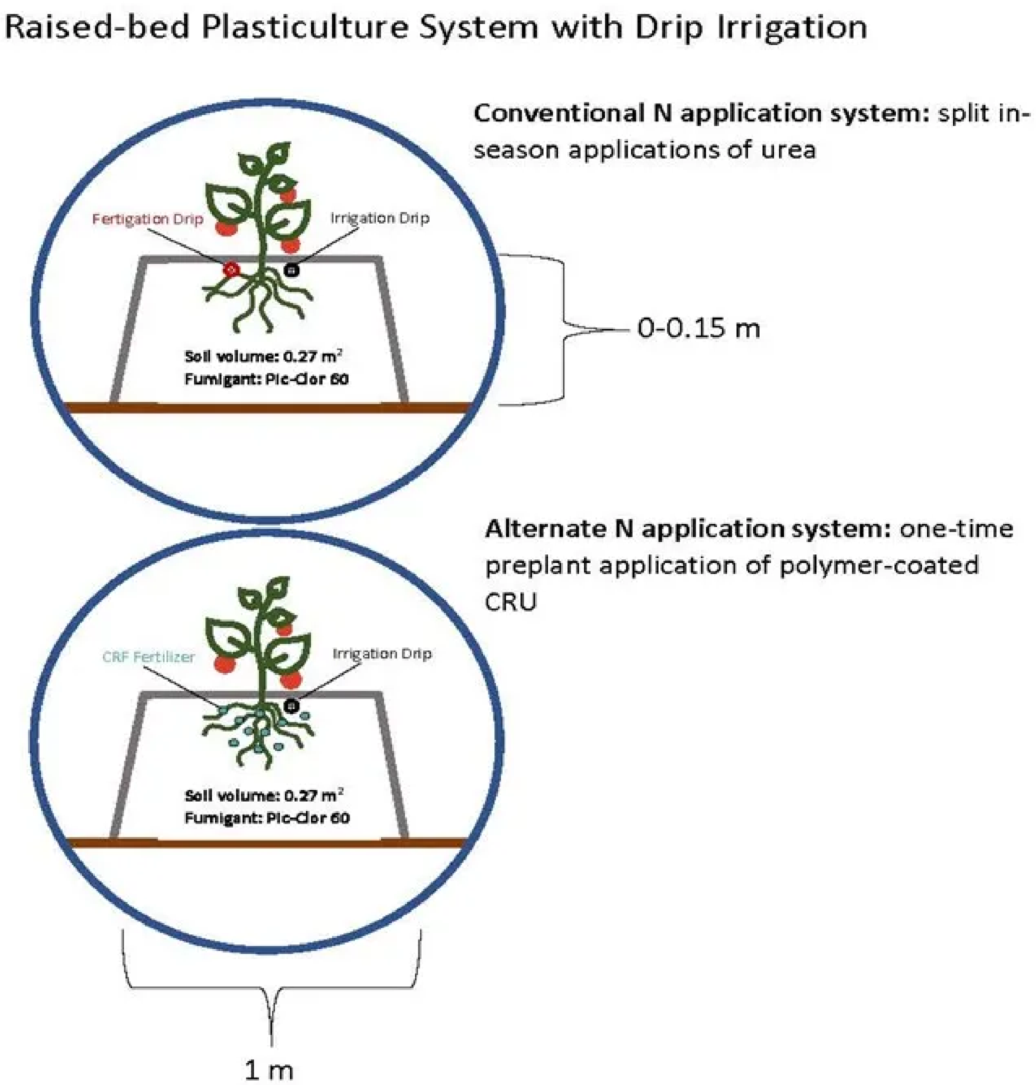

Figure 2. Schematic of a raised-bed plasticulture system with drip irrigation, illustrating both the conventional N application system using fertigated soluble urea and the alternative system utilizing controlled-release fertilizer.
Credit: Christian Bartell, UF/IFAS, and Laura Jalpa, formerly UF/IFAS

The FDACS BMP manual has identified the use of CRFs as an approved BMP of N management for agricultural crops in Florida. Our study aimed to confirm the suitability and compatibility for use in intensively managed vegetable production systems in north Florida.

For practical guidance on how to implement the 4Rs in your tomato cultivation, refer to EDIS publication SL411, "The Four Rs of Fertilizer Management."

The following sections elaborate on the study findings. Each component of N management plays a critical role in maximizing both crop yield and environmental sustainability. Find further details on tomato production from this study in Jalpa et al. (2024).

N Rate

Nitrogen is the only major essential nutrient that does not have a reliable soil test for recommending fertilizer amounts due to its rapid transformations (e.g., nitrification and denitrification) and translocations (e.g., leaching and runoff) in nature (Jalpa et al. 2021). Determining the optimal N rate is crucial for maximizing NUE and ensuring healthy tomato crop development. Adjusting N application rates to match the specific needs of tomato plants can significantly enhance growth and reduce waste from over-fertilization.

The following are strategic approaches to choosing nitrogen application rates:

1. **Adjusting to Plant N Needs:** In north Florida, where sandy soils predominate, excessive N can easily leach below the rootzone. Our research indicates that applying N at the UF/IFAS recommended rate of 200 lb/ac is sufficient (Mylavarapu et al. 2021) (Table 1).
2. **Benefits of N Application in Multiple Equal Split Doses:** Such an approach not only ensures that plants receive sufficient nutrients but also aligns with the needs of the crop during growth periods, leading to the minimization of leaching potential. Furthermore, minimizing N losses also translates into cost-effective fertilization, avoiding unnecessary expenditure on unused fertilizer.

This efficient use of N fosters sustainable farming practices, which are particularly important in regions with sensitive ecosystems or where water pollution from agricultural runoff or leaching is a concern. Growers should adapt their fertilization strategy based on ongoing assessments of plant health and growth patterns. This responsive approach helps apply N more precisely, ensuring the crop gets exactly what it needs when it needs it.

N Source

The type of N source significantly impacts both efficiency and environmental impact. Systems using prevalent drip irrigation commonly utilize soluble N sources such as urea (Figure 3) since they are cost-effective and have high N content (46-0-0). Urea is available in granular, soluble, and polymer-coated controlled-release (CRU) forms, each offering different benefits. For instance, polymer-coated CRUs (Figure 3) release N in response to temperature changes, which affect plant growth rates, providing a consistent and predictable release pattern that can be tailored to last for 60 to 120 days. This feature makes CRUs particularly useful in areas like north Florida, where they have been shown to perform similarly to weekly fertigation applications of soluble N in vegetable fields. Our research demonstrated that CRUs can be as effective as soluble N sources for tomato yield and quality. Given these advantages, growers can confidently choose CRUs as an efficient and environmentally friendly alternative N source to enhance crop yields, agreeing with current BMP guidelines.

Here are a few steps to consider when choosing a CRU for your farming operation.

1. **Understand crop needs:** Choose a CRU product that matches the growth duration and seasonal N demand profile of the chosen crop. For instance, if the crop cycle is relatively short, a CRU formulation with a quicker N release might be appropriate. Conversely, a CRU that ensures a steadier, prolonged release might be more beneficial for longer growing seasons.
2. **Ask for product specifications:** When selecting a CRU, ask suppliers for detailed product specifications and release curves. This information can help you understand how the product will behave under various temperature and moisture conditions.
3. **Consult local Extension services:** Engage the local county agricultural agent and the specialists with insights into the site-specific conditions and climate factors affecting N release from CRUs. These professionals can provide guidance based on recent field studies and crop modeling specific to the region.
4. **Check for reviews or case studies:** Look for reviews or case studies from other vegetable growers who use CRUs. Learning from others' experiences can provide practical insights into which products perform best under conditions similar to yours.
5. **Conduct a trial and get feedback:** Once you have an idea of the CRU formulation you would like to use, consider trialing the CRU on a smaller scale before fully integrating it into practice. Monitor the crop response in relation to the yields. (See EDIS publication HS964, "Plant Tissue Analysis and Interpretation for Vegetable Crops in Florida.") Also, carefully monitor the impacts of irrigation. If necessary, adjust the irrigation practices to prevent over-irrigating, which can displace small doses of N

from CRUs beyond the rootzone. (See EDIS publication HS917, "Drip Irrigation: The BMP Era—An Integrated Approach to Water and Fertilizer Management for Vegetables Grown with Plasticulture.") Feedback from these trials can help fine-tune strategies for efficient fertilizer management under site-specific conditions.

Figure 3. Urea (Harrell's LLC, Lakeland, Florida, USA; **left**) and polymer-coated controlled-release urea (POLYON®, Harrell's LLC, Lakeland, Florida, USA; **right**).
Credit: Laura Jalpa, formerly UF/IFAS

N Application Time

To achieve optimal NUE, ensuring that soluble N applications are carefully timed to coincide with the specific uptake patterns of tomato plants is crucial. Typically, these plants exhibit increased N demand during their reproductive stages (e.g., flowering and fruit development) (Figure 4). Effectively aligning N delivery with these peak demand periods can significantly enhance the ability of plants to utilize N, leading to improved growth, higher yields, and reduced losses to the environment.

The strategy to maximize NUE involves two effective approaches, particularly suited to the agricultural conditions in north Florida. Both strategies are optimized by using lower N rates, which enhance their effectiveness:

1. **Frequent, Small Doses of Fertigated Urea:** This method involves applying soluble N in small quantities at weekly intervals through fertigation systems. This approach keeps N levels consistent and available throughout their growth cycle, especially during critical growth phases.
2. **A Single Preplant Application of CRU:** Alternatively, using CRU involves a one-time application of N before planting. CRUs are engineered to release N slowly over an extended period, matching the release with growth and crop uptake stages. This approach simplifies crop nutrition management by eliminating the need for the frequent applications required by conventional fertilizers, thereby reducing labor and streamlining management processes. Our research indicates that a single preplant application of CRU can achieve tomato yields comparable to those from multiple fertigations of a soluble N source.

Figure 4. The commercial round tomato cultivar 'HM 1823'. Meeting the crop N requirements of tomatoes during critical developmental periods enhances NUE. For guidance on selecting commercial tomato varieties for Florida production, refer to chapter 18 of the *Vegetable Production Handbook of Florida*, "Tomato Production."
Credit: Laura Jalpa, formerly UF/IFAS

N Placement

The effectiveness of N fertilizers is greatly influenced by their placement, which should be carefully considered based on the type of fertilizer and the specific field, nutrient, and water management system used. Precision in N placement can significantly impact crop yield and nutrient efficiency for tomato and other vegetable growers using raised-bed plasticulture systems with drip irrigation.

The following strategies maximize NUE through effective nitrogen placement:

1. **Placement with Fertigated Soluble Urea:** Placement is closely tied to the irrigation rate for soluble N sources. Precise application is crucial to avoid excessive irrigation and N losses, which not only waste valuable nutrients but can also lead to environmental contamination. Soluble N should be applied in sync with the irrigation amount and schedule to ensure it wets the soil just enough to reach the roots and deeper down the soil profile.

2. **Utilizing Controlled-Release Urea (CRU):** CRU offers a more forgiving application method due to its gradual-release properties. When using CRUs, placing the fertilizer within the raised bed before applying the mulch and planting the crop—within a soil area of 2.9 ft^2—ensures that the CRU prills remain in continuous contact with the tomato roots (Figure 2). This placement of the fertilizer in the bed under the mulch is critical (Figure 5) because it leverages the physical barrier provided by the plastic mulch, which prevents the CRU prills from being washed away during heavy rains and helps to maintain the structural integrity of the soil.

In our research, both fertilizer placement strategies effectively kept N within the rootzone, maximizing its availability to the crops and enhancing fertilizer efficiency. This placement proved particularly advantageous when applying fertilizers at lower N rates.

Figure 5. Controlled-release urea prills were broadcast onto the rough beds and then incorporated during final bed formation.
Credit: Laura Jalpa, formerly UF/IFAS

Optimizing NUE Through Seasonal Adjustments

NUE is influenced by the natural characteristics of the soil and the prevailing weather conditions. In north Florida, where seasonal rainfall variations can significantly impact soil nutrient dynamics, tailoring N application strategies can greatly enhance crop performance and efficiency (Jalpa et al. 2020).

Fall Production

In fall, when temperatures are cooler and soil mineralization rates are lower, tomatoes tend to rely more on externally applied N. The conventional fertigated urea applications in smaller doses have proven particularly effective in this season. Such an approach minimizes N losses and ensures that the applied N is readily available to the crop.

Spring Production

During spring, warmer temperatures and increased soil microbial activity often lead to higher natural N mineralization rates. This means the soil itself releases more readily available N than in the fall. In such conditions using conventional systems, lower NUE values ranging from 28.9% to 45.3% of the total applied N indicate that much of the crop's N demand is being met from the soil itself. In such conditions, the alternate N application system using CRU was found to be more advantageous. Seasonal averages for spring and fall based on the three N rates (125, 150, and 200 lb/acre) did not differ significantly. CRU-75 was applied once preplant, and NUE was calculated as total plant N uptake divided by N applied. The release rate of N is directly proportional to the soil temperature, thereby releasing relatively higher amounts during warmer periods that coincide with active growth phases and higher N uptake by the crop (Figure 6A). Data were derived from a mesh bag study evaluating N release by weight under plastic-mulched raised beds. Mean soil temperatures at each growth stage were included to show seasonal conditions. Note that by the time of planting, approximately 18% of N had already been released, as CRU was incorporated during the fumigation process three weeks prior to transplanting.

This controlled-release mechanism helps prevent N loss that could occur with quicker-release forms (e.g., soluble urea) under more dynamic spring soil conditions. By using CRUs, growers can enhance NUE (42.3%–72.0%) during spring, improving efficiencies significantly compared to conventional methods. The beneficial effects of controlled-release sources as a BMP are more pronounced during the warmer production months in north Florida.

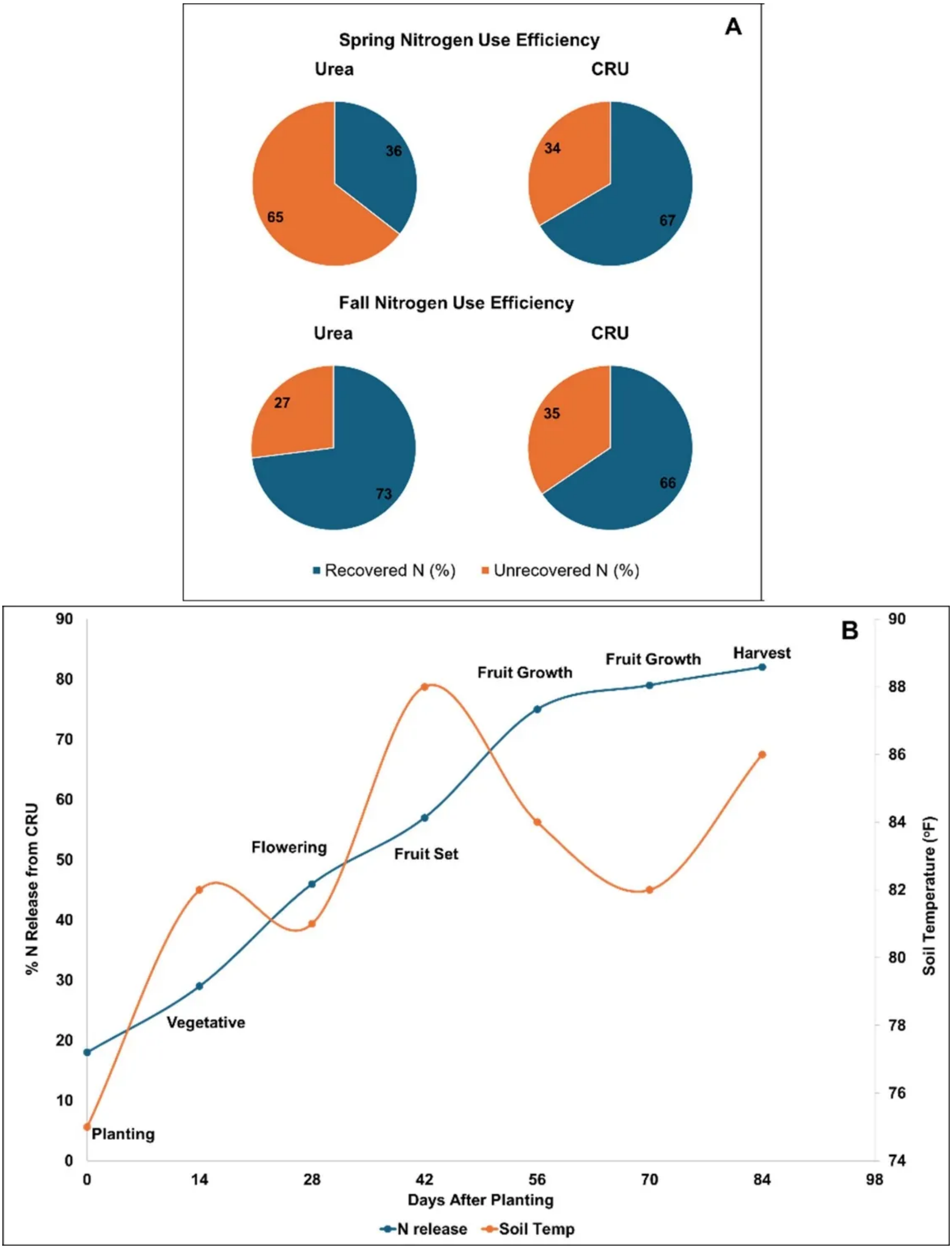

Figure 6. (A) Nitrogen use efficiency (NUE) for polymer-coated controlled-release urea with a 75-day release duration (CRU-75) in fresh-market tomato production in north Florida. Values represent seasonal averages for spring and fall across three nitrogen rates (125, 150, and 200 lb/acre), which did not differ significantly. CRU-75 was applied once preplant, and NUE was calculated as total plant nitrogen uptake divided by nitrogen applied. (B) Nitrogen release from CRU-75 during spring 2021. Data originate from a mesh bag study measuring nitrogen release by weight under plastic-mulched raised beds. Mean soil temperatures at each growth stage are shown to indicate seasonal conditions. Approximately 18% of nitrogen had been released by planting due to incorporation during fumigation three weeks before transplanting.
Credit: Credits: (A) Adapted from Jalpa et al. (2024, Table 9) and (B) Jalpa et al. (2024, Figure 2).

Conclusions

For sustainable cost-effective tomato production, efficient and targeted N management is essential. Utilizing polymer-coated CRU and traditional soluble urea applications, combined with adapting to seasonal conditions, has proven effective in maintaining economical yields across different seasons. This approach highlights the importance of timing N applications to sync with the active crop growth stages. Also, the role of educational programs through county Extension offices is crucial for success.

Take-Home Messages

Polymer-Coated CRU as a Viable Alternative: The one-time application of polymer-coated CRU at preplant can produce comparable yields to multiple fertigation applications of soluble urea. CRUs are particularly effective in reducing labor and environmental impacts associated with frequent fertilizer applications.

Seasonal Variations in N Efficiency: Using CRU as an N source is likely to help overcome the variations in NUE between spring and fall seasons.

Effect of Application Timing on NUE: Seasonal adjustments to N application strategies can enhance NUE. For instance, a 13-week split application of urea in the fall and a full N rate application of CRUs before planting in the spring can lead to enhanced N efficiency in tomatoes.

Effect of Application Placement on NUE: Both conventional and alternative N strategies maintain constant contact of N in the rootzone, leading to similar N accumulations and NUE.

N Budgets to Guide N Fertilization Practices for Local Crop Production: Understanding soil mineralization and crop N uptake patterns is crucial for crafting effective fertilization strategies specifically tailored to the unique demands of both the crop and the local environmental conditions. This information allows for precise adjustments in N application, ensuring optimal crop health and yield. If detailed data on soil mineralization and crop N uptake is not readily available in your area, contacting your local Extension office can provide you access to this information and additional support.

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Table 1. Summary of the conventional and alternative N fertilizer application programs. All data collected is for the commercial tomato cultivar 'HM 1823'.

4Rs	Conventional program	Alternative program
Rate	125, 150, 200 lb/ac	125, 150, 200 lb/ac
Source*	Urea (46N-0P-0K)	CRU**-60 (43-0-0)
	Urea (46N-0P-0K)	CRU-75 (42-0-0)
Time	Urea was applied 1 week after planting and was split into 13 weekly doses during the season.	CRU was applied one time at the full (100%) N rate at preplant during bed preparation.
Placement	Fertigation***	CRU prills were broadcast onto the false beds and then incorporated during bed formation.
*Urea: Harrell's LLC, Lakeland, Florida, USA; CRU: POLYON®, Harrell's LLC, Lakeland, Florida, USA **CRU = Controlled-release urea ***Fertigation = the application of nutrients through the drip-irrigation system		

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