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Localized organo-mineral fertilization maintains ultra-early watermelon yield while reducing mineral nitrogen input under temporary film cover

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Cultivating ultra-early watermelon (*Citrullus lanatus*) in arid continental climates requires both early-season thermal protection and efficient nutrient management to ensure high yield while limiting excessive mineral fertilizer inputs. This study, conducted during the 2022–2024 growing seasons in the Karshi steppe of Uzbekistan, evaluated the performance of five ultra-early watermelon hybrids under a temporary double-layer plastic film cover used as a background technology, while comparing conventional broadcast fertilization with localized organo-mineral fertilization applied per planting nest. A randomized complete block design was employed, testing five hybrids under identical film-covered conditions. Fertilization treatments included a standard broadcast application (10 t ha^{-1} manure + $N_{150}P_{120}K_{75}$) and localized nest-based organo-mineral fertilization with reduced mineral NPK rates. Marketable yield, earliness, and fruit quality were assessed over three seasons. Localized fertilization significantly increased vegetative growth and marketable yield compared with broadcast application, despite a 30–40% reduction in total mineral nitrogen input. The hybrids Krimstar F1 and Montana F1 achieved the highest yields (26.1 and 25.4 t ha^{-1}, respectively). Importantly, fruit quality was not adversely affected: total soluble solids (TSS) remained stable across treatments (7.4–7.5%), indicating that yield gains did not compromise internal quality. These

results demonstrate that localized organo-mineral fertilization under temporary film cover can maintain high productivity of ultra-early watermelon while reducing mineral nitrogen inputs. The approach represents an agronomically efficient and environmentally safer fertilization strategy for early watermelon production in arid continental agro-ecosystems.

KEYWORDS

genotype × environment × management, nest-based nutrient application, nutrient-use efficiency, organo-mineral fertilization, semi-arid cropping systems, sustainable agronomy, temporary plastic film cover, ultra-early watermelon

1 Introduction

Watermelon (*Citrullus lanatus* (Thunb.) Matsum. & Nakai) is one of the most economically significant cucurbit crops globally, particularly in arid and semi-arid regions where water resources are limited. In recent years, the consumer demand for early-season produce has driven a shift toward "ultra-early" cultivation systems. Producing watermelons 20–30 days ahead of the main season offers farmers a substantial economic advantage due to premium market prices. However, early spring cultivation in continental climates, such as that of Central Asia, faces severe abiotic constraints, primarily low soil temperatures and unstable thermal regimes during the seedling establishment phase (Díaz-Pérez, 2022).

To mitigate these thermal limitations, plasticulture technologies —specifically the use of low tunnels and plastic mulching—have become a standard agronomic practice. Studies have demonstrated that covering the soil surface significantly increases the accumulation of growing degree days (GDD), accelerates root metabolism, and promotes precocious fruit ripening (Zhang et al., 2024; Houshyar and Bacenetti, 2023).

In this study, the term "thermos method" refers to the use of a temporary double-layer polyethylene film cover applied during early spring to increase soil and near-surface air temperature, protect seedlings from low night temperatures, and accelerate early vegetative development. While the thermal microclimate has been extensively studied, the optimization of nutrient management within these protected systems remains a critical challenge.

Watermelon is a nutrient-demanding crop, and traditional fertilization practices in the region often involve the broadcast application of high rates of mineral nitrogen (N) and phosphorus (P). This conventional approach frequently results in low Nutrient Use Efficiency (NUE) due to volatilization and leaching, posing environmental risks such as soil salinization and groundwater contamination (Wang et al., 2022). Furthermore, excessive mineral fertilization can negatively impact soil microbial diversity and fruit quality, leading to a "dilution effect" of sugars (Hou et al., 2024).

Therefore, developing sustainable intensification strategies that reduce mineral input without compromising yield is imperative. Recent research suggests that localized fertilization—placing nutrients directly into the planting "nest" or rhizosphere zone—can enhance nutrient uptake efficiency by synchronizing supply with the plant's immediate demand (Song et al., 2022). Localized (per-nest) organo-mineral fertilization involves placing a defined amount of organic matter combined with reduced mineral NPK directly in the root zone at planting, aiming to synchronize nutrient availability with early root growth and improve nutrient uptake efficiency during the critical early growth stages.

However, despite the widespread use of temporary plastic film covers and organic or mineral fertilizers in early vegetable production, limited information is available on the optimal integration of localized organo-mineral fertilization with ultra-early watermelon hybrids under arid continental conditions.

The proposed approach is based on the hypothesis that improved thermal conditions under temporary film cover stimulate early root system development, which in turn enhances the efficiency of localized nutrient uptake.

This interaction is expected to support early biomass accumulation and fruit formation while allowing a reduction in total mineral nitrogen input without compromising fruit quality.

The objective of this study was to identify adaptive ultra-early watermelon hybrids and optimize the fertilization rate per nest to ensure high productivity and fruit quality under the specific soil-climatic conditions of the Karshi steppe.

2 Materials and methods

2.1 Study site and soil conditions

The field experiment was conducted during three consecutive growing seasons (2022–2024) at the experimental station of Karshi State University, located in the Karshi district of the Kashkadarya region, Uzbekistan (approximate coordinates: 38°52′N, 65°48′E). The region is characterized by an arid continental climate with rapid temperature accumulation in early spring.

The soil of the experimental site is classified as irrigated meadow-alluvial (local classification), characterized by a

groundwater table depth of 2.0–3.0 m. The soil texture is medium loam with low salinity. Pre-plant soil analysis (0–30 cm depth) indicated a low humus content of 0.9–1.1%, total nitrogen of 0.08–0.10%, available phosphorus of 18–22 mg kg^{-1}, and exchangeable potassium of 200–215 mg kg^{-1} (Figure 1).

2.2 Plant material and experimental design

The study evaluated five ultra-early watermelon (Citrullus lanatus) hybrids: Montana F1, Talisman F1, Dolby F1, Hollar-Crimson Sweet, and Krimstar F1. These hybrids were selected for their potential adaptability to early-season stressors and rapid maturation rates.

A randomized complete block design (RCBD) with three replications was employed. The total area of each experimental plot was 73.5 m^2. Seeds were sown during the first decade of March (March 1–10) using the "thermos" method. This technique involves a double-layer polyethylene film cover to optimize soil temperature and moisture retention, a practice widely cited for enhancing seedling emergence in early-season cucurbits (Díaz-Pérez, 2022; Zhang et al., 2024).

The experiment followed a factorial arrangement with two factors: watermelon hybrid and fertilization strategy.

Five ultra-early hybrids were evaluated under identical microclimatic conditions, while fertilization method constituted the main management factor.

In both fertilization treatments all plots were managed under the same temporary double-layer film cover; thus, the film acted as a common background technology, while the only experimental factor was the fertilization strategy (broadcast versus localized per nest).

The temporary film cover was applied uniformly to all plots and was therefore not treated as an experimental factor.

The planting scheme followed a double-row system: (280 + 70)/2 × 70 cm, resulting in a plant density of approximately 8,160 plants ha^{-1}.

2.3 Fertilization treatments

To assess nutrient use efficiency and yield response, two distinct fertilization strategies were compared:

1. Control (Conventional Broadcast Application): Organic manure was applied at 10 t ha^{-1} during tillage. Mineral fertilizers were applied at the standard regional recommendation of $N_{150}P_{120}K_{75}$ kg ha^{-1} via broadcasting.
2. Optimized (Localized/Nest Application): A localized fertilization approach was implemented to reduce total mineral input while maintaining nutrient availability in the root zone (Hou et al., 2024). This treatment involved applying 1.0 kg of organic manure per nest (hill), combined with reduced rates of mineral fertilizers calculated per plant: $N_{13.0–15.8}P_{10.5–12.6}K_{6.6–8.0}$ grams per nest. This method targets the "rhizosphere effect," aiming to improve nutrient uptake efficiency in the early developmental stages.

The ranges reported for per-nest NPK rates reflect minor adjustments based on hybrid-specific plant density and nest spacing, ensuring comparable nutrient supply per unit area across treatments.

Based on the established plant density, localized per-nest fertilization resulted in a 30–40% lower total mineral nitrogen input per hectare compared with the conventional broadcast fertilization practice.

2.4 Measurements and data collection

Phenological observations were recorded according to standard agronomic protocols. Germination, flowering (male and female), and fruit setting dates were documented when 10% (onset) and 75% (full stage) of the plant population reached the respective stage.

Biometric measurements were conducted at the flowering and fruit ripening stages on 10 representative plants per plot. Parameters included main vine length (cm), number of leaves per plant, and leaf area (m^2). Leaf area was estimated using linear dimensions according to established methodological guidelines for cucurbits.

Total marketable yield was harvested in June. Fruit quality was assessed by measuring the Total Soluble Solids (TSS) content using a hand-held refractometer (expressed in Brix %), which is a key indicator of watermelon internal quality and consumer acceptance.

2.5 Statistical analysis

Data from the 2022–2024 growing seasons were subjected to analysis of variance (ANOVA) in a randomized complete block design to test the main effects of hybrid, fertilization method and year, as well as their interactions. A combined ANOVA across years was performed, treating year as a random factor. Because the interaction between year and treatment was not significant for the studied traits, the results are presented as three-year means. Statistical processing followed the methodology of Dospekhov (1985), and treatment means were separated using Fisher's Least Significant Difference (LSD) test at $p < 0.05$.

Hybrid and fertilization strategy were treated as fixed effects, while year and block were considered random factors.

Mean comparisons were performed using Fisher's LSD test at $P \leq 0.05$, which is appropriate for factorial field experiments with a limited number of treatments.

In this study, nutrient-use efficiency was assessed indirectly through the ratio between marketable yield and total applied mineral nitrogen per unit area, allowing comparison of fertilization strategies under identical growing conditions.

3 Results

3.1 Vegetative growth dynamics

The vegetative development of ultra-early watermelon hybrids was significantly influenced by both the genotype and the fertilization method. The biometric measurements taken during the fruit ripening stage revealed that the localized (per nest) application of organo-mineral fertilizers promoted more vigorous growth compared to the conventional broadcast method.

As shown in Table 1, the main vine length across all hybrids ranged from 218 cm to 292 cm under the optimized fertilization regime, whereas under the control conditions, it ranged from 195 cm to 268 cm.

Differences among fertilization strategies were statistically significant ($p < 0.05$), while variation among hybrids reflected genotype-specific growth potential.

The hybrid Krimstar F1 exhibited the longest main vine (292 cm) under localized fertilization, which differed significantly from the broadcast treatment within the same hybrid ($p < 0.05$).

Similarly, the assimilation surface area (leaf area) — a critical parameter for photosynthetic efficiency — was positively affected by the localized nutrient application. Leaf area per plant ranged from 0.74 to 0.82 m^2 under localized fertilization, compared with lower values under broadcast fertilization, corresponding to an increase of approximately 8–12%.

Montana F1 and Talisman F1 showed the highest leaf area values, indicating stronger vegetative development under identical early-season growing conditions.

3.2 Yield performance and earliness

The analysis of yield components indicated that the "thermos" method combined with nest-fertilization significantly accelerated crop maturation and increased marketable yield. Because the film cover was applied uniformly across all treatments, differences in crop performance are attributed to fertilization strategy rather than to thermal protection effects.

The appearance of the first marketable fruits in the localized fertilization treatments occurred 3–5 days earlier than in the broadcast fertilization plots, which is agronomically relevant for ultra-early production systems.

Total marketable yield varied significantly among the studied hybrids (Figure 2). The optimized fertilization strategy resulted in yields ranging from 22.7 to 26.1 t ha^{-1}, whereas the conventional method produced between 19.8 and 23.4 t ha^{-1}.

The highest productivity was recorded for Krimstar F1 (26.1 t ha^{-1}) and Montana F1 (25.4 t ha^{-1}) under localized fertilization. LSD analysis confirmed that yield differences between fertilization strategies were statistically significant at $p < 0.05$.

These results indicate that placing nutrients directly in the root zone enhances crop productivity under ultra-early cultivation conditions, consistent with improved fertilizer efficiency.

3.3 Fruit quality characteristics

Fruit quality, particularly sugar content expressed as total soluble solids (TSS), is a key determinant of consumer acceptance. The results indicate that increased yields under localized fertilization did not lead to a reduction in fruit quality.

A common concern in intensive vegetable production systems is the potential "dilution effect," whereby increased yields may be accompanied by a reduction in fruit sugar concentration. In the present study, however, higher yields obtained under localized fertilization were not associated with a decline in Total Soluble Solids (TSS). Across the evaluated hybrids, TSS values remained within a relatively narrow range, indicating that fruit sweetness was maintained despite yield enhancement.

TABLE 1 Effect of fertilization strategy on vegetative growth parameters of ultra-early watermelon hybrids (three-year mean, 2022–2024).

Hybrid (Alphabetical)	Fertilizer rate per nest	Main vine length (cm)	Number of lateral shoots (pcs)	Leaf area per plant (m2)	Root mass (g)
Dolby F1	Optimized	205	4.6	0.28	149.5
	Control (Broadcast)	208	4.8	0.28	152.4
Hollar-Crimson	Optimized	215	4.8	0.29	151.2
	Control (Broadcast)	220	4.9	0.30	155.8
Krimstar F1	Optimized	292	5.3	0.35	165.4
	Control (Broadcast)	298	5.5	0.36	170.1
Montana F1	Optimized	217	5.1	0.30	158.3
	Control (Broadcast)	222	5.2	0.30	162.5
Talisman F1	Optimized	210	5.0	0.29	156.5
	Control (Broadcast)	217	5.1	0.29	161.8
LSD 0.05		1.2–2.5			

Values represent three-year means. Differences between fertilization strategies within the same hybrid were evaluated using LSD test at $p \leq 0.05$.



FIGURE 1
General view of the experimental site showing ultra-early watermelon cultivation under temporary double-layer film covers ("thermos" method), photographed in March 2023 during the early vegetative stage. Plot labels indicate hybrid names and fertilization treatments.

The graphical results (Figure 3) provide the primary quantitative evidence for TSS stability, while the photographic assessment of fruit internal quality (Figure 4) offers a representative visual illustration of flesh color and refractometer-based measurements at harvest maturity. These images should be interpreted as supportive, qualitative documentation rather than standalone evidence of treatment effects.

The maintenance of TSS under localized fertilization may be related to a more balanced nutrient supply in the root zone, particularly adequate potassium availability during the fruit-filling stage. Nevertheless, since the present study did not directly quantify carbohydrate partitioning or enzymatic activity related to sugar metabolism, this interpretation should be considered indicative rather than mechanistic.

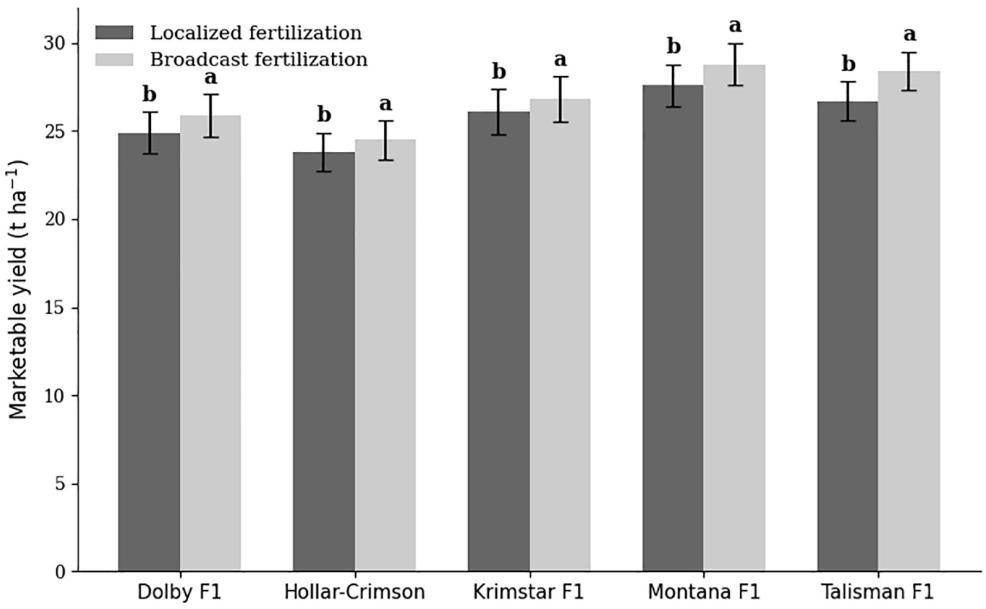


FIGURE 2
Marketable yield of ultra-early watermelon hybrids under localized (optimized) and broadcast (control) fertilization strategies. Bars represent mean values ± standard deviation (SD). Different letters indicate significant differences between fertilization strategies within the same hybrid at $p \leq 0.05$ according to Fisher's LSD test.

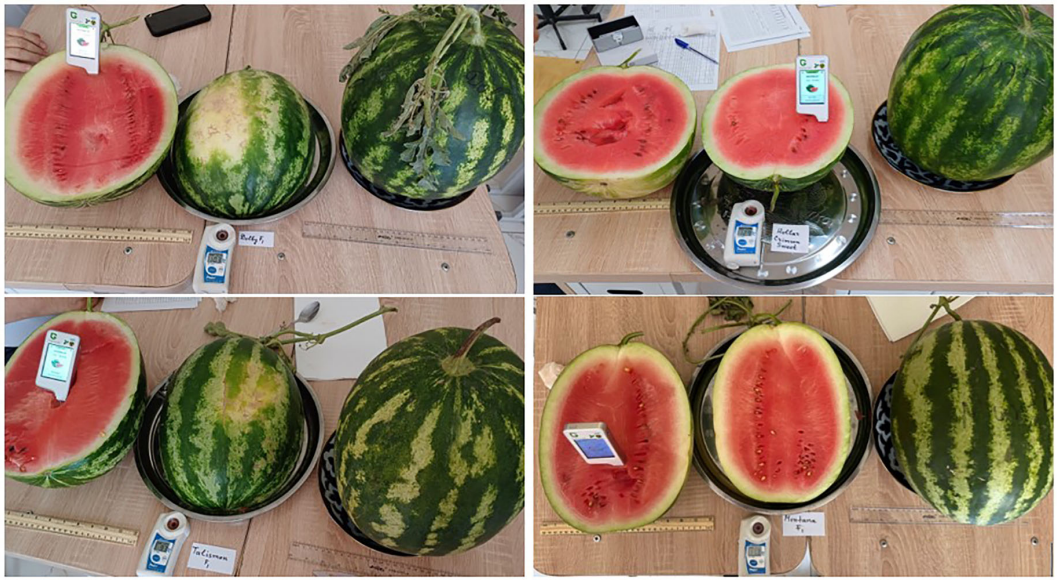


FIGURE 3
Nitrate content in fruits of ultra-early watermelon hybrids under localized (optimized) and broadcast (control) fertilization strategies. Bars represent mean values ± standard deviation (SD). The dashed line indicates the maximum permissible nitrate limit (60 mg kg^{-1}).

4 Discussion

4.1 Microclimate modification and earliness

The primary objective of ultra-early watermelon cultivation is to overcome the thermal limitations of early spring. In this study, earlier harvest (3–5 days) was observed under localized fertilization while all treatments were grown under identical temporary film-cover conditions.

Therefore, differences in earliness cannot be attributed solely to the film cover itself, which served as a background technology rather than an experimental factor.

Díaz-Pérez (2022) reported that plastic mulches and low tunnels effectively increase soil temperature and accumulate

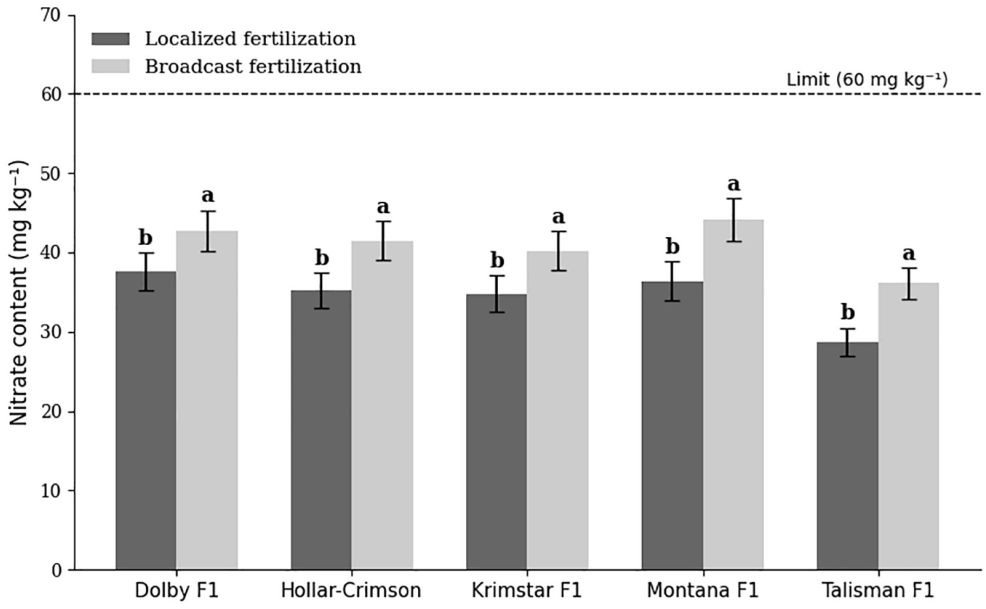


FIGURE 4
Representative internal fruit quality assessment of ultra-early watermelon hybrids under localized and broadcast fertilization strategies, photographed at harvest maturity in June 2023. The images illustrate fruit flesh color and refractometer-based Total Soluble Solids (TSS) measurements.

growing degree days (GDD), which are critical for cucurbit establishment in cool seasons. Our findings are consistent with this general understanding of plasticulture systems, although the present experiment did not include a no-cover control to directly quantify the independent effect of film cover on phenology.

Zhang et al. (2024) emphasized that optimizing root-zone temperature through film covering enhances root metabolic activity and nutrient uptake. In the present study, enhanced vegetative growth observed under localized fertilization likely reflects improved nutrient availability under favorable early-season thermal conditions, rather than a distinct film-cover effect.

4.2 Nutrient use efficiency through localized fertilization

A key finding of this study is that localized (per nest) fertilization maintained, and in some cases exceeded, the yield obtained from conventional broadcast application, despite a significant reduction in total mineral nitrogen input. Conventional broadcasting often leads to low Nitrogen Use Efficiency (NUE) due to leaching and volatilization, a problem highlighted by Wang et al. (2022) in arid zone agriculture. Similar conclusions regarding the limited yield response to increased nitrogen inputs have been reported by Giraldo-Sanclemente et al. (2025).

In our experiment, the optimized localized treatment reduced the mineral nitrogen dose by approximately 30–40% compared with the conventional broadcast recommendation, while maintaining or even increasing total marketable yield. This outcome indicates a higher agronomic efficiency of applied nitrogen, as reflected by greater yield per unit of mineral N input.

Although nitrate leaching and soil nitrogen dynamics were not directly measured in this study, a reduction in applied mineral nitrogen is generally associated with a lower potential risk of nitrogen losses in irrigated arid environments.

Therefore, the observed yield response suggests that localized fertilization may contribute to more sustainable nutrient management under ultra-early watermelon production systems.

Our data suggest that placing nutrients directly in the "nest" (rhizosphere zone) ensures a higher availability of nutrients during early root development. This observation is consistent with Hou et al. (2024), who reported that reduced chemical fertilizer combined with organic amendments can improve watermelon yield.

However, potential effects on soil microbial diversity or nutrient cycling were not assessed in the present study and should be considered as prospective research directions rather than confirmed mechanisms.

4.3 Genotypic adaptability and yield potential

The differential performance of hybrids highlights the importance of genotype selection for specific environmental conditions. Krimstar F1 and Montana F1 consistently exhibited greater vine length and higher yield under localized fertilization.

These differences reflect genotype-specific responses to nutrient management rather than direct evidence of physiological mechanisms such as heterosis or hydraulic conductance, which were not measured in this study.

Nevertheless, the observed stability of these hybrids across seasons suggests that they possess favorable traits for ultra-early production under arid continental conditions.

Similar varietal differences have been reported by Luna et al. (2024). While such studies indicate that genetic traits may influence water and nutrient relations, the present results should be interpreted primarily at the agronomic performance level.

The ability of Krimstar F1 to achieve high yields (26.1 t ha^{-1}) under reduced mineral nitrogen input indicates its suitability for resource-efficient production systems, rather than a direct quantification of genetic NUE.

4.4 Balancing yield and fruit quality

A common trade-off in agronomy is the "dilution effect," where higher yields are associated with reduced sugar or nutrient concentrations in fruits. In the present study, no statistically significant decline in Total Soluble Solids (TSS) was observed between fertilization strategies, despite higher yields under localized fertilization.

TSS values remained within a narrow range (7.4–7.5%) for hybrids such as Montana F1, indicating that fruit sweetness was maintained.

These results suggest that yield improvement achieved through localized fertilization did not adversely affect internal fruit quality.

Potassium is known to play a role in sugar translocation (Song et al., 2022). Although potassium dynamics were not directly quantified, balanced NPK application in the root zone may have supported assimilate transport during fruit filling, contributing to the maintenance of TSS levels.

5 Conclusion

This study demonstrates that ultra-early watermelon production in the arid soils of Uzbekistan can be improved by integrating adaptive F1 hybrids (particularly Krimstar F1 and Montana F1) with a localized "nest" fertilization strategy under temporary film-cover conditions.

The proposed approach offers the following advantages:

1. Agronomic: It achieves high marketable yields (up to 26.1 t ha^{-1}), while maintaining fruit quality as indicated by stable total soluble solids (TSS > 7.0%) across fertilization strategies.
2. Environmental: By reducing mineral nitrogen inputs by approximately 30–40% compared with the conventional broadcast regime, the approach is expected to lower the

potential risk of nitrate leaching and secondary soil salinization, although these processes were not directly measured in the present study.

Although the present experiment was conducted at a single site in the Karshi steppe, its soil–climatic conditions are representative of many irrigated arid and semi-arid agro-ecosystems in Central Asia. Therefore, the proposed fertilization strategy shows promise for broader application under similar conditions; however, multi-location field trials are required to confirm its robustness and scalability across different environments.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

TO: Supervision, Methodology, Writing – review & editing, Conceptualization, Resources, Writing – original draft. DU: Writing – original draft, Data curation, Writing – review & editing, Investigation, Methodology. XA: Data curation, Resources, Investigation, Writing – review & editing. AS: Writing – review & editing, Software, Formal Analysis, Validation. SI: Project administration, Conceptualization, Validation, Writing – review & editing, Supervision. IL: Data curation, Writing – review & editing, Investigation. NS: Writing – review & editing, Formal Analysis, Software. AI: Writing – review & editing, Investigation, Resources. ST: Data curation, Writing – original draft, Investigation. MX: Validation, Writing – review & editing, Formal Analysis. IA: Visualization, Validation, Writing – review & editing.

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Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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References

Díaz-Pérez, J. C. (2022). Plant growth and fruit yield of watermelon as influenced by colored plastic film mulch. *Int. J. Vegetable Science.* 29, 84–92. doi: 10.1080/19315260.2022.2117756

Dospekhov, B. A. (1985). *Methodology of field experience (with the basics of statistical processing of research results). 5th Ed* (Moscow: Agropromizdat).

Giraldo-Sanclemente, W., Pérez-Castillo, A. G., Elizondo-Barquero, M., and Rodríguez-Solis, C. M. (2025). Coffee yield is influenced by soil properties, not by nitrogen fertilization strategies, under greenhouse gas monitoring in a Costa Rican Andisol. *Front. Agronomy.* 7. doi: 10.3389/fagro.2025.1729122

Hou, D., Su, D., and Hao, K. (2024). Reduced chemical fertilizer combined with vermicompost application affects the growth, yield, and quality of watermelon. *Hortic. Science.* 34, 1–9. doi: 10.21273/HORTTECH05441-24

Houshyar, E., and Bacenetti, J. (2023). Efficiency analysis of watermelon under plastic film mulching systems. *Cleaner Environ. Systems.* 8, 100107. doi: 10.1016/j.cesys.2023.100107

Luna, E., Guan, W., Camberato, J., and Dong, Y. (2024). Effects of irrigation and fertigation on seedless watermelon yield in Southern Indiana. *Hortic. Science.* 34, 604–612. doi: 10.21273/HORTTECH05483-24

Song, X., Wang, Q., Luo, J., Guo, D., and Ma, Y. (2022). Effect of fertilizer application on watermelon growth, structure of dissolved organic matter and microbial functional diversity in organic substrates. *Sustainability* 14, 6951. doi: 10.3390/su14126951

Wang, X., Liu, R., Luo, J., Zhu, P., Wang, Y., Pan, X., et al. (2022). Effects of water and NPK fertigation on watermelon yield, quality, irrigation-water, and nutrient use efficiency under alternate partial root-zone drip irrigation. *Agric. Water Management.* 271, 107785. doi: 10.1016/j.agwat.2022.107785

Zhang, Q., Masabni, J., and Niu, G. (2024). Organic fertilizer type and dose affect growth, morphological and physiological parameters, and mineral nutrition of watermelon seedlings. *PeerJ* 12, e16902. doi: 10.7717/peerj.16902