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DOSE-DEPENDENT TITHONIA-EGGSHELL INTERACTIONS INFLUENCE CHERRY TOMATO YIELD UNDER DRIP IRRIGATION

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ABSTRACT

Circular nutrient strategies that combine plant-derived fertilizers with mineral-rich food waste may reduce dependence on conventional inputs, but their interaction can be dose-sensitive. This study evaluated liquid organic fertilizer (LOF) from Tithonia diversifolia and chicken eggshell powder on cherry tomato under drip irrigation. A factorial randomized block design used four nutrient regimes (N0 = AB mix comparator; N1 = 500 ppm Tithonia LOF; N2 = 1000 ppm; N3 = 1500 ppm) and two eggshell levels (C0 = 0; C1 = 50 g plant-1), with three blocks. Plant height and stem diameter were recorded at 4-8 weeks after planting (WAP), fruit number and fruit weight were evaluated across three harvest observations, and post-treatment soil organic C, total N, and C/N ratio were measured. Tithonia regime affected plant height at 4 and 6 WAP but not stem diameter. Neither main factor affected fruit number or fruit weight; however, their interaction was significant for both yield variables. N1C0 produced the highest numerical fruit number (5.44 plant-1), whereas N0C1 produced the highest fruit weight (14.50 g plant-1); N1C1 produced the lowest fruit weight (7.52 g plant-1), revealing a crossover rather than uniformly synergistic response. Soil chemistry showed descriptive increases in organic C and total N and a decline in C/N toward N3C1. Baseline pH differed among treatment allocations and was therefore not interpreted as a treatment effect. These findings show that recycling Tithonia biomass and eggshell waste in drip-irrigated cherry tomato requires dose-specific pairing; combining organic inputs does not automatically improve yield.

Keywords: cherry tomato; Tithonia diversifolia; eggshell; drip irrigation; organic fertilization.

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INTRODUCTION

Cherry tomato (Solanum lycopersicum) is a high-value horticultural crop whose attractiveness is linked not only to fruit size and taste but also to its concentrations of lycopene, vitamin C, carotenoids, and other antioxidant compounds (Yang et al., 2023). In Indonesia, efforts to improve cherry tomato productivity increasingly focus on combinations of plant growth inputs, nutrient management, and resource-efficient cultivation. A recent study published in Algebra showed that cherry tomato growth and yield can respond differently to gibberellin and humic acid, emphasizing that crop performance depends on the specific combination and concentration of inputs rather than on their presence alone (Azhari et al., 2025). This interaction-sensitive response is particularly relevant when alternative organic nutrient sources are introduced into intensive tomato production.

Water management is another central constraint because tomato productivity is sensitive to both insufficient and excessive water. Drip irrigation supplies water directly to the root zone and can improve water-use efficiency while maintaining productive growth. Automated drip irrigation has produced substantial water savings relative to conventional irrigation in tomato (Suvitha et al., 2021), and deficit-drip studies have demonstrated trade-offs among vegetative growth, yield, fruit quality, and water productivity (Wu et al., 2021). Drip-line configuration and irrigation amount can also alter yield and irrigation water-use efficiency (Guo et al., 2022). More broadly, water and fertilization are not independent management factors: optimized combinations of irrigation and organic or mineral fertilization can improve tomato yield and nitrogen-use efficiency (Wu et al., 2022).

The search for nutrient sources that reduce reliance on synthetic fertilizer has increased interest in locally available biomass and food-processing residues. Organic fertilization can improve soil organic matter, nutrient cycling, biological activity, and crop productivity, while contributing to circular use of agricultural residues (Gamage et al., 2023; Liu et al., 2024). Tithonia diversifolia (Mexican sunflower, locally known as kipahit or paitan) is a rapidly growing biomass resource that can be fermented into liquid organic fertilizer. Experimental work with Tithonia leaf extract has shown concentration-dependent responses in crop growth and yield, including non-linear responses in soybean (Ramayana et al., 2023), while Tithonia-containing liquid fertilizer has also supported shallot production (Mutia et al., 2024). Such findings indicate that higher organic fertilizer concentration should not automatically be assumed to produce a superior crop response.

Eggshell waste provides a complementary nutrient-management pathway because it is rich in calcium carbonate. Ground eggshell can raise soil pH under acidic conditions and perform a liming function comparable with agricultural lime in controlled soil studies (Sebonela et al., 2024). Crop studies have likewise reported growth or yield responses to eggshell amendments in tomato and cherry tomato (Nursayuti et al., 2023; Wulandari & Ratnasari, 2023; Afif & Mulyani, 2026). However, eggshell effects depend on particle size, dissolution, soil acidity, application rate, nutrient background, and duration. A factorial tomato experiment with eggshell and Mucuna bracteata liquid organic fertilizer found interaction-specific yield responses (Syahputri et al., 2024), whereas a moringa-liquid-fertilizer and eggshell study did not consistently improve mustard growth (Suhastyo & Raditya, 2021). Therefore, eggshell is not a universally positive additive and must be evaluated within the nutrient system in which it is used.

Factorial designs are particularly useful for identifying this type of conditional response. An Algebra study on beet demonstrated that concentration and application method can interact strongly even when single-factor interpretations would be incomplete (Hasibuan et al., 2024). For cherry tomato, little information is available on the combined use of fermented Tithonia LOF and eggshell powder under a controlled drip-irrigation regime. The novelty of the present study lies in testing whether eggshell addition modifies the response curve to Tithonia LOF rather than merely asking whether either input works independently. The study therefore aimed to determine the main and interactive effects of Tithonia LOF concentration and eggshell powder on cherry tomato vegetative growth and yield under drip irrigation, while descriptively examining associated soil organic C, total N, and C/N characteristics. We hypothesized that the response to eggshell would depend on the Tithonia nutrient regime, producing a dose-dependent interaction in yield.

RESEARCH METHODS

Study site and experimental design. The experiment was conducted from March to June 2026 at the Experimental Garden of the Faculty of Science and Technology, Universitas Tjut Nyak Dhien, Medan, Indonesia. A factorial randomized block design was used with two treatment factors and three replications. Factor N represented the nutrient regime: N0 = AB mix comparator, N1 = 500 ppm

Tithonia diversifolia LOF, N2 = 1000 ppm Tithonia LOF, and N3 = 1500 ppm Tithonia LOF. Factor C represented eggshell powder: C0 = no eggshell and C1 = 50 g plant-1. The factorial arrangement produced eight treatment combinations. The experiment comprised 24 plots, 96 plants in total, and 72 designated sample plants.

Growing medium and crop establishment. Cherry tomato seedlings were raised for approximately 14 days before transplanting. Each planting unit used a 40 cm x 50 cm polybag containing 5 kg of a topsoil:rice-husk:cocopeat mixture at a 3:4:3 ratio. Healthy, uniform seedlings with three to four leaves were transplanted and maintained using routine weeding, staking, replacement of damaged plants during establishment, and pest or disease control when required.

Preparation and application of Tithonia LOF and eggshell. Tithonia plant material was chopped and fermented with clean water, coconut water, dissolved brown sugar, and EM4 bioactivator in a closed container. The fermentation mixture was mixed regularly, then filtered before use. The resulting LOF was supplied according to the assigned nutrient concentration through the nutrient reservoir; solution was replenished as the reservoir volume declined. Eggshell waste was sun-dried, ground to a fine powder, and applied around the planting medium at transplanting according to the C treatment.

Drip irrigation. A gravity-fed drip system was installed so that each polybag received water near the root zone. The system was checked for uniform delivery before the experiment. Irrigation was maintained at approximately 2 L plant-1 day-1, divided between morning and afternoon applications. Drip irrigation was used to reduce variability in water placement and to isolate the nutrient-treatment responses as far as possible. This rationale is consistent with evidence that drip irrigation can improve tomato water productivity when delivery is appropriately controlled (Suvitha et al., 2021; Wu et al., 2021).

Measurements. Plant height (cm) and stem diameter (mm) were measured at 4, 5, 6, 7, and 8 WAP. Fruit number per plant was counted over three harvest observations. Fruit weight per plant (g) was obtained from the fruit-weight measurements recorded across the same harvest period following the original thesis protocol. Soil organic C was measured by the Walkley-Black method and total N by the Kjeldahl method; the C/N ratio was calculated from these measurements. The available pH dataset is explicitly labelled as initial soil pH in the original annex and represents baseline measurements. Because those values preceded treatment exposure, baseline pH was retained only to document initial heterogeneity and was not interpreted as an effect of Tithonia LOF or eggshell.

Statistical analysis. Growth and yield data were analyzed using factorial analysis of variance for a randomized block design: Yijk = mu + rhoi + alphaj + betak + (alphabeta)jk + epsilonijk, where block, Tithonia nutrient regime, eggshell, and their interaction were included in the model. When the F test indicated significance, treatment means were separated using Duncan's Multiple Range Test (DMRT) at the 5% level (Duncan, 1955). The original appendices show square-root transformation for fruit number and fruit weight; inferential statements for these yield variables therefore follow the transformed ANOVA, while tables present the original-scale means for interpretability. Post-treatment organic C, total N, and C/N values were available as laboratory values by treatment combination without replicate-level inferential output, so they are discussed descriptively rather than subjected to unsupported significance testing.

RESULTS AND DISCUSSION

Vegetative growth response. Tithonia nutrient regime significantly affected plant height at 4 and 6 WAP, whereas no significant main effect was detected at 5, 7, or 8 WAP. At 4 WAP, N2 (1000 ppm) and the AB mix comparator N0 formed the highest DMRT group. At 6 WAP, N0 was highest, followed by N1, while N2 and N3 were lower. Eggshell did not significantly affect plant height at any measurement time, and the Tithonia x eggshell interaction was also non-significant for height. Stem diameter was not significantly affected by either main factor or their interaction from 4 to 8 WAP (Table 1).

Table 1. Selected cherry tomato growth responses to Tithonia LOF and eggshell

Treatment	Height 4 WAP (cm)	Height 6 WAP (cm)	Height 8 WAP (cm)	Stem diameter 8 WAP (mm)
N0 (AB mix)	15.25 a	61.35 a	91.75	9.49
N1 (500 ppm)	10.41 b	51.82 b	85.83	9.04
N2 (1000 ppm)	15.73 a	44.33 c	77.50	8.38
N3 (1500 ppm)	10.31 b	43.58 c	76.25	8.82
C0 (0 g eggshell)	12.38	50.54	83.04	9.09
C1 (50 g eggshell)	13.47	50.00	82.63	8.77

Note. Within the Tithonia (N) main-effect rows, means followed by different letters differ according to DMRT at 5% for columns where the factor was significant. No letters are shown for non-significant comparisons. WAP = weeks after planting.

The temporal pattern indicates that Tithonia LOF changed early vegetative growth but did not maintain a consistent advantage through 8 WAP. This is agronomically plausible because organic-liquid inputs can release nutrients at rates that differ from immediately available mineral nutrient formulations. Organic fertilizers can improve nutrient supply and soil processes, but their response depends on mineralization, microbial transformations, and nutrient synchronization with crop demand (Dinca et al., 2022; Liu et al., 2024). In the present experiment, the AB mix comparator provided the greatest height at 6 WAP and the highest numerical height at 8 WAP, suggesting that the soluble mineral nutrient regime may have provided more immediately balanced nutrition during rapid vegetative growth. The absence of a monotonic increase from 500 to 1500 ppm Tithonia is consistent with the broader principle that increasing organic nutrient concentration does not necessarily increase plant performance. Ramayana et al. (2023), for example, reported a concentration-dependent Tithonia response rather than a simple linear increase.

The lack of an eggshell effect on height and stem diameter does not imply that eggshell is agronomically inactive. Ground eggshell can modify acidity because its dominant mineral phase is calcium carbonate, but dissolution and reaction are time- and environment-dependent. Sebonela et al. (2024) demonstrated a clear liming response when eggshell was incubated in acidic soils, whereas crop responses can differ under shorter pot experiments and when nutrient supply is already substantial. Studies in tomato have reported positive eggshell responses under some fertilizer combinations (Nursayuti et al., 2023; Afif & Mulyani, 2026), while Suhastyo and Raditya (2021) found no consistent improvement in mustard growth from eggshell-containing liquid fertilizer. These contrasting results reinforce the need to interpret eggshell as a context-dependent amendment rather than an intrinsically growth-promoting input.

Yield interaction. The most important result was the interaction between Tithonia nutrient regime and eggshell. The main effects of Tithonia and eggshell were not significant for fruit number or fruit weight, but their interaction was significant at the 5% level for both variables. This means that the effect of adding eggshell changed depending on the nutrient regime and, conversely, the apparent response to Tithonia concentration depended on whether eggshell was present (Table 2).

Table 2. Interaction means for fruit number and fruit weight per plant

Combination	Nutrient regime / eggshell	Fruit number (plant-1)	Fruit weight (g plant-1)
N0C0	AB mix / 0 g	3.56 ab	10.03 bc
N0C1	AB mix / 50 g	5.22 a	14.50 a
N1C0	500 ppm / 0 g	5.44 a	14.24 a
N1C1	500 ppm / 50 g	2.44 b	7.52 d
N2C0	1000 ppm / 0 g	3.78 ab	10.74 bc
N2C1	1000 ppm / 50 g	5.22 a	13.40 ab
N3C0	1500 ppm / 0 g	5.00 a	13.49 ab
N3C1	1500 ppm / 50 g	3.44 b	9.27 c

Note. Means within each yield column followed by different letters differ according to DMRT at 5%. Original-scale means are shown; significance follows the transformed ANOVA reported in the study appendices.

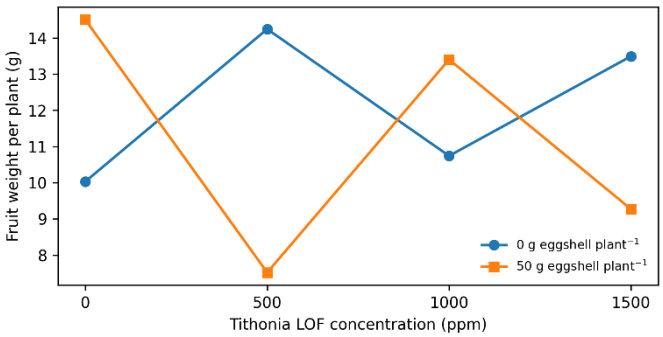


Figure 1. Crossover response of cherry tomato fruit weight to Tithonia LOF and eggshell

The interaction is clearly a crossover rather than a uniform synergy (Figure 1). Eggshell increased fruit weight in the AB mix comparator from 10.03 to 14.50 g plant-1 and at 1000 ppm Tithonia from 10.74 to 13.40 g plant-1. In contrast, eggshell decreased fruit weight at 500 ppm from 14.24 to 7.52 g plant-1 and at 1500 ppm from 13.49 to 9.27 g plant-1. Fruit number followed a similar conditional pattern: the highest numerical value occurred in N1C0 (5.44 fruit plant-1), while N1C1 had the lowest value (2.44 fruit plant-1). Therefore, a recommendation based only on the eggshell main-effect mean or only on the Tithonia main-effect mean would conceal the agronomically important result.

Interaction-specific nutrient responses have been observed in other crop systems. Hasibuan et al. (2024) reported that concentration and application method interacted for several beet growth and production variables, while Syahputri et al. (2024) found an eggshell-by-liquid-organic-fertilizer interaction for tomato yield. Wulandari and Ratnasari (2023) also demonstrated that eggshell-containing treatments can modify cherry tomato productivity when paired with another growth input. The present experiment extends that interaction perspective to a Tithonia-based organic nutrient system under drip irrigation and shows that a waste-derived calcium amendment can be beneficial in one nutrient background yet unfavorable in another.

Several mechanisms could contribute to the crossover, although the present dataset cannot distinguish among them. First, calcium carbonate from eggshell may alter rhizosphere chemical conditions and thereby modify the availability of phosphorus and micronutrients. Sebonela et al. (2024) showed that eggshell can raise pH and influence phosphorus availability in acidic soils. Second, Tithonia LOF supplies a mixture of mineralized and organic nutrient forms whose availability changes during decomposition. Organic amendments alter microbial community activity and nutrient transformations (Dinca et al., 2022), and their carbon-to-nitrogen stoichiometry influences nitrogen mineralization (Smith et al., 2024). Third, combining two inputs can change nutrient balance even when each input is individually reasonable; excess or asynchronous nutrient supply can reduce efficiency. In drip-irrigated tomato, irrigation-fertilization combinations have been shown to affect yield, nitrogen uptake, and resource-use efficiency, supporting the need to evaluate water and nutrient management jointly (Wu et al., 2022).

From a practical perspective, the N1C0 and N0C1 treatments are noteworthy for different reasons. N1C0 achieved the greatest numerical fruit number and a top-group fruit weight without eggshell, suggesting that 500 ppm Tithonia LOF can support reproductive performance under the tested conditions. N0C1 achieved the greatest fruit weight, indicating that eggshell may complement a balanced mineral nutrient solution. However, N1C1 performed poorly, so the data do not support recommending the simultaneous use of 500 ppm Tithonia LOF and 50 g eggshell per plant. The result also cautions against describing the two organic materials as synergistic without qualification. The more accurate interpretation is dose-dependent compatibility.

Baseline pH and post-treatment soil chemistry. The thesis dataset contains a table labelled initial soil pH, with values that already differed among the groups allocated to the treatment combinations (Table 3). Because these measurements were obtained before treatment exposure, they cannot validly be used to claim that Tithonia LOF or eggshell caused a pH change. The manuscript therefore treats pH only as a baseline characteristic. This correction is important because a true treatment effect on pH requires a post-treatment measurement, preferably evaluated relative to baseline or with baseline included as a covariate when appropriate.

Table 3. Baseline pH and descriptive post-treatment soil chemical values

Combination	Baseline pH	Organic C (%)	Total N (%)	C/N
N0C0	4.53	1.33	0.14	9.50
N0C1	4.07	1.35	0.14	9.64
N1C0	5.90	1.35	0.16	8.44
N1C1	4.93	1.37	0.17	8.06
N2C0	5.87	1.35	0.19	7.11
N2C1	4.83	1.38	0.19	7.26
N3C0	5.27	1.37	0.25	5.48
N3C1	5.13	1.41	0.26	5.42

Note. Baseline pH values were measured before treatment exposure and are not treatment outcomes. Organic C, total N, and C/N are post-treatment laboratory values reported by treatment combination; no replicate-level inferential statistics were available for these soil endpoints.

Post-treatment laboratory values showed a narrow rise in organic C from 1.33% in N0C0 to 1.41% in N3C1 and a larger numerical rise in total N from 0.14% in N0C0/N0C1 to 0.26% in N3C1. At the same time, C/N declined from a maximum of 9.64 in N0C1 to 5.42 in N3C1. These patterns are consistent with increasing nitrogen contribution and altered organic-matter stoichiometry as the Tithonia concentration increased, but they must be regarded as descriptive because the soil values were not available with replicate-level statistical support. Organic fertilizers can increase soil organic matter and modify nutrient availability (Hsu & Lai, 2022; Gamage et al., 2023), while lower amendment C/N ratios are generally associated with more rapid nitrogen mineralization when other conditions are favorable (Smith et al., 2024).

The soil pattern also helps explain why a simple 'more organic input is better' conclusion is not warranted. The highest Tithonia concentration was associated descriptively with the highest total N and lowest C/N, yet it did not produce the highest plant height or fruit weight. Crop response is governed by nutrient balance, timing of release, root-zone chemistry, water status, and physiological demand rather than by total nutrient concentration alone. Reviews of organic fertilization emphasize that benefits arise through interacting physical, chemical, and biological pathways (Liu et al., 2024), and drip-irrigation studies similarly show that the crop response to fertilization depends on water management and nutrient synchronization (Wu et al., 2022).

The study has four limitations that should guide future work. First, N0 was an AB mix comparator rather than a zero-nutrient control, so the experiment compares Tithonia LOF regimes with a conventional nutrient solution but cannot quantify absolute fertilizer effects relative to an unfertilized control. Second, the baseline pH heterogeneity and absence of a clearly documented post-treatment pH dataset prevent causal conclusions about soil pH. Third, post-treatment organic C, total N, and C/N were available as treatment-level laboratory values without replicate-level inferential analysis. Fourth, the trial was conducted in polybags over one growing cycle and three harvest observations, so field-scale yield, long-term soil effects, and economic performance remain to be tested. Future experiments should include an unfertilized control, repeated pre- and post-treatment pH measurements, replicated soil chemistry, and a wider eggshell dose range. Testing Tithonia LOF composition directly for N, P, K, Ca, electrical conductivity, and pH would also improve mechanistic interpretation.

Despite these limitations, the interaction pattern has practical and scientific value. Current sustainability approaches increasingly emphasize recycling locally available organic residues while maintaining crop productivity (Gamage et al., 2023). Tithonia biomass and eggshell waste fit this circular-resource concept, but the present findings show that compatibility must be empirically optimized. This is particularly important for intensive horticulture, where small changes in nutrient availability can influence reproductive allocation. The study therefore contributes a more nuanced novelty claim: Tithonia LOF and eggshell are not simply alternative fertilizers; their agronomic value in cherry tomato is conditional on dose-specific pairing under a defined irrigation regime.

CONCLUSIONS

Under drip irrigation, Tithonia diversifolia liquid organic fertilizer altered cherry tomato plant height at 4 and 6 WAP but did not significantly affect stem diameter. Eggshell powder at 50 g plant-1 had no consistent main effect on vegetative growth or yield. The key result was a significant Tithonia x eggshell interaction for fruit number and fruit weight. The highest numerical fruit number occurred at 500 ppm Tithonia without eggshell (N1C0), whereas the highest fruit weight occurred with AB mix plus eggshell (N0C1). Adding eggshell to 500 ppm Tithonia markedly reduced both yield variables,

demonstrating a crossover response and showing that the two recycled inputs should not be described as universally synergistic. Post-treatment soil data descriptively indicated higher organic C and total N and a lower C/N ratio at higher Tithonia regimes. Initial pH values were retained only as baseline information and were not interpreted as treatment effects. For practical application, Tithonia LOF and eggshell should be optimized as a paired nutrient system rather than recommended independently; further replicated trials should quantify post-treatment pH, nutrient composition, field-scale yield, and economic efficiency before broad recommendation.

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