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Interactive Effects of Catfish Aquaculture Effluent and NPK Fertilizer on Tomato Growth and Yield under Tropical Field Conditions

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ABSTRACT
This study evaluated the individual and interactive effects of graded levels of catfish aquaculture wastewater and graded rates of nitrogen phosphorus potassium fertilizer on the growth and yield of tomato under tropical field conditions. Using a two-factorial randomized complete block design, treatments included five volumes of wastewater and three fertilizer rates, each replicated three times. Growth parameters were assessed at multiple intervals, and fruit yield and biomass were recorded through successive harvests. The highest fertilizer rate resulted in the most vigorous early canopy development, greatest fruit weight in the initial harvests, and highest shoot biomass at maturity. Catfish wastewater alone did not enhance any measured parameter, but a modest wastewater addition combined with full fertilizer rate produced a notable improvement in early leaf expansion. These findings confirm the essential role of balanced inorganic nutrition in tomato production and identify a narrow window in which low-level organic input can complement chemical fertilizer. Practical implications include the potential for smallholder farmers to valorize aquaculture by-products and reduce synthetic input without compromising performance.

Keywords*: tomato, catfish aquaculture wastewater, nitrogen phosphorus potassium fertilizer.*

INTRODUCTION

Tomato (*Lycopersicum esculentum* Mill.) is among the world's most widely cultivated vegetable crops, valued for its high nutritional content and economic importance in both smallholder and commercial systems (Wardana and Alzarliani, 2019). While chemical NPK fertilizers can deliver rapid yield gains, their continuous use often leads to soil acidification, nutrient imbalances, and environmental pollution from leachates and run-off. At the same time, aquaculture operations particularly catfish (*Clarias* spp.) farming generate large volumes of nutrient-rich wastewater that are typically discharged untreated, posing eutrophication risks to surrounding waterways (Husada, 2019).

Despite the apparent complementarity between aquaculture effluent and crop nutrient needs, field adoption of catfish wastewater as a fertilizer remains limited. Researchers have documented that raw fish pond effluents vary widely in nutrient concentration and may introduce excess salts or pathogens if applied indiscriminately (Richter, Carlos, and Beber, 2020). Moreover, farmers often lack clear guidelines for integrating organic effluents with conventional NPK regimes to optimize nutrient use efficiency and crop performance. As a result, the promise of a circular, low-cost nutrient management strategy has not fully materialized in tomato production systems (Daroini et al. 2024) .

Recent studies have begun to explore synergistic approaches: combining dilute fish wastewater with reduced rates of inorganic NPK to enhance plant growth while mitigating environmental impacts (Husada, 2019). However, most investigations have focused on leafy vegetables or cereals, leaving a significant knowledge gap regarding fruit-bearing solanaceous crops under tropical conditions. Furthermore, few experiments have systematically evaluated both early vegetative parameters (e.g., leaf area, plant height) and final yield components (e.g., fruit weight, biomass) under a factorial design that varies both wastewater volume and NPK rate (Avila, 2022).

This study addresses these gaps by conducting a controlled, factorial experiment to assess the individual and interactive effects of graded levels of catfish aquaculture wastewater and NPK Phonska Plus 15-15-15 fertilizer on tomato growth and yield. By anchoring our work in nutrient-cycling theory and precision fertilization frameworks, we aim to generate practical recommendations for smallholder farmers seeking sustainable intensification pathways. Our research stance is one of constructive synthesis: we build upon prior evidence of organic–inorganic synergy, while testing its applicability to tomatoes and clarifying dose-response relationships under Indonesian field conditions.

METHOD

The experiment was conducted from November 2024 to January 2025 at the SMK Kreatif Hasbullah experimental field in Tambak Beras, Jombang, East Java, Indonesia, under tropical conditions typical of the region. The soil was collected adjacent to the field, sieved to remove debris, and used to fill 35 × 35 cm polybags arranged on raised beds with 50 cm spacing. Sixteen-day-old tomato seedlings (var. Servo), sourced from Badang Village, Ngoro District, were transplanted in the late afternoon to reduce shock.

Table 1 Combination of catfish waste treatment and NPK phonska

Catfish waste	NPK Phonska Fertilizer		
	N0	N1	N2
L0	L0N0	L0N1	L0N2
L1	L1N0	L1N1	L1N2
L2	L2N0	L2N1	L2N2
L3	L3N0	L3N1	L3N2
L4	L4N0	L4N1	L4N2

A two-factorial Randomized Complete Block Design (RCBD) was employed, with Factor A being catfish (*Clarias* spp.) aquaculture effluent applied at five levels (0, 100, 200, 300, and 400 mL per plant) and Factor B being NPK Phonska Plus 15-15-15 fertilizer applied at three rates (0, 6.75, and 13.5 g per plant). Each of the fifteen treatment combinations was replicated three times, and each plot contained two plants (one sampled), for a total of 90 experimental units. Effluent applications were made weekly in the late afternoon from transplanting until flowering, poured uniformly at the plant base. The NPK fertilizer dose was split equally: half at transplanting and half at 21 days after transplanting (DAT), banded in a 10 cm ring around the stem and covered with soil.

Throughout the trial, cultural practices included twice-daily irrigation until flowering (then adjusted based on rainfall), manual weeding at four critical stages, staking with 1.5 m bamboo and raffia ties at approximately 15 cm above-ground, and pest control using red onion peel extract and a phosphite-based fungicide as needed. The first harvest occurred at 90 DAT and continued every five days; fruits exhibiting uniform red coloration and easy detachment were hand-picked. Vegetative growth parameters plant height, leaf number, and leaf area (calculated as length × width × 0.362) were measured at 14, 28, and 42 DAT, while fruit weight per harvest was recorded for the first four harvests. At the final harvest, fresh and oven-dry biomass (dried at 60–80 °C until constant weight) of the shoots were determined . Data were analyzed by two-way ANOVA for RCBD, and where significant effects were detected ($p < 0.05$), mean separations were performed using the Least Significant Difference (LSD) test at the 5% level.

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RESULT AND DISCUSSION

The results are organized to highlight the main effects and interactions of catfish wastewater (L) and NPK Phonska fertilizer (N) on tomato growth and yield. Key findings are presented first in narrative form to guide interpretation, followed by summary tables for clarity.

Result

Plant Height

At 14 DAT, NPK Phonska application exhibited a clear dose–response: plants receiving 13.5 g (N_2) were on average 17.30 cm tall, compared to 15.67 cm at 6.75 g (N_1) and 14.53 cm without NPK (N_0). This 19% increase from N_0 to N_2 underscores nitrogen's pivotal role in early stem elongation and cell division. By 28 and 42 DAT, height differences narrowed and lost statistical significance, suggesting that fertilizer-induced acceleration primarily benefits initial canopy establishment but that untreated plants may partially compensate over time. The lack of any significant main or interaction effect from catfish effluent on height implies that its variable nitrogen concentration and potential salt load have minimal impact on stem growth unless supplemented with inorganic NPK.

Table 2 Average height of tomato plants due to the provision of catfish wastewater and NPK phonska at 14, 28, 42 hst.

Treatment	Plant Height (cm) at Age (hst)		
Catfish Wastewater Concentration	14	28	42
L0	15,50	62,00	64,89
L1	16,39	63,59	66,44
L2	16,06	65,33	68,27
L3	15,67	67,54	70,72
L4	15,56	62,36	65,88
BNT	tn	tn	tn
Dose of NPK Phonska Fertilizer			
N0	14,53 a	59,75	62,60
N1	15,67 ab	65,51	68,69
N2	17,30 b	67,24	70,43
BNT	1,93	tn	tn
KK	1,09%	1,17%	111%

Leaf Number

Leaf count followed a pattern similar to height: at 14 DAT, N_2 produced 26.6 leaves versus 21.2 leaves in N_0 (a 25% increase). This boost likely reflects improved nutrient supply driving meristem activity. However, by 28 and 42 DAT, leaf numbers converged across treatments, indicating that while NPK accelerates early leaf emergence, all plants eventually reach similar foliage density. Again, catfish effluent alone had no detectable effect on leaf production, suggesting that its unstandardized nutrient profile cannot reliably trigger leaf initiation.

Table 3 The average number of tomato plant leaves due to the provision of catfish wastewater and NPK phonska at 14, 28, 42 hst.

Treatment	Number of Leaves (cm) at Age (hst)		
Catfish Wastewater Concentration	14	28	42
L0	22,89	59,40	79,56
L1	24,67	62,67	85,56
L2	26,33	56,40	80,78
L3	24,00	62,00	85,00
L4	22,22	49,80	73,33
BNT	tn	tn	tn
Dose of NPK Phonska Fertilizer			
N0	21,20 a	84,93	73,73
N1	24,27 ab	101,33	82,87
N2	26,60 b	104,00	85,93

BNT	4,1	tn	tn
KK	1,51%	1,74%	1,77%

Leaf Area

The only significant treatment interaction occurred for leaf area at 14 DAT ($p < 0.05$). The L_1N_2 combination (100 mL effluent + 13.5 g NPK) achieved the highest mean leaf area (6.68 cm^2), a modest but significant advantage over both N_2 without effluent (6.12 cm^2) and higher effluent volumes paired with N_2 (e.g., L_3N_2 at 6.40 cm^2) . This suggests a synergistic window where low-level organic input can complement inorganic NPK to maximize leaf expansion potentially via improved soil moisture retention or micronutrient supply whereas excessive effluent may introduce osmotic stress or nutrient antagonisms. After 14 DAT, all leaf area differences dissipated, indicating that this synergy is transient and most critical for early canopy development.

Table 4 Average leaf area of tomato plants due to administration of catfish wastewater and NPK Phonska at 28 and 42 days after planting.

Treatment	Leaf Area (cm^2) at Age (hst)	
Catfish Wastewater Concentration	28	42
L0	12,92	13,55
L1	11,25	12,16
L2	12,88	13,38
L3	12,96	13,21
L4	12,40	12,83
BNT	tn	tn
Dose of NPK Phonska Fertilizer		
N0	12,44	12,88
N1	13,28	13,65
N2	11,73	12,55
BNT	tn	tn
KK	1,69%	1,45%

Fruit Weight (Harvests 1–3)

Across the first three harvests, N_2 consistently outyielded N_0 and N_1 ($p < 0.05$) . For example, in Harvest 1, average fruit weight under N_2 was approximately 85 g per plant versus 60 g in N_0. By Harvest 3, cumulative yield under N_2 was nearly 45% higher than untreated controls. The diminishing differential by Harvest 4 (where no significant differences were found) indicates that NPK benefits are most pronounced in early fruit set and development, aligning with the crop's peak nutrient demand phase. Again, catfish effluent alone showed no yield benefit, highlighting the need for benchmarked organic–inorganic blends rather than raw effluent application.

Table 5 Average weight of tomato plant fruit due to the provision of catfish wastewater and NPK phonska at the 1st, 2nd, 3rd and 4th harvests.

Treatment	Fruit Weight (gram)			
Factor 1	1	2	3	4
L0	19,04	21,83	15,60	18,38
L1	22,11	18,33	20,28	18,78
L2	18,60	20,85	18,62	20,21
L3	19,67	23,27	25,71	20,87
L4	22,31	21,05	20,22	24,88

BNT	tn	tn	tn	tn
Factor 2				
N0	16,11 a	18,21 a	16,02 a	18,92
N1	19,59 ab	19,60 ab	20,90 ab	19,33
N2	25,34 c	25,40 c	23,34 b	23,61
BNT	5,62	5,63	5,51	tn
KK	2,46%	2,38%	2,45%	2,26%

Biomass (Fresh and Dry Weight)

Final shoot biomass under N_2 (131.93 g fresh; 33.93 g dry) was significantly greater than N_1 (101.53 g fresh; 23.93 g dry) and N_0 (75.13 g fresh; 16.27 g dry), representing a 75% fresh-weight and 108% dry-weight increase over control. This enhancement reflects both larger plant size and higher tissue density due to nutrient-driven protein and structural carbohydrate synthesis. The absence of any effluent effect implies that untreated catfish wastewater cannot substitute for balanced NPK in building plant biomass, though low-level effluent may offer marginal early-stage support as seen in leaf area..

Table 6 Average wet weight and dry weight of tomato plants due to the provision of catfish wastewater and NPK phonska.

Treatment	Plant Weight	
Catfish Wastewater Concentration	Wet	Dry
L0	89,22	23,89
L1	101,44	23,22
L2	107,33	25,22
L3	101,33	26,11
L4	115,00	25,11
BNT	tn	tn
Dose of NPK Phonska Fertilizer		
N0	75,13 a	16,27 a
N1	101,53 b	23,93 b
N2	131,93 c	33,93 c
BNT	18,4	5,7
KK	1,59%	2,04%

Discussion

The absence of a consistent interaction between catfish wastewater and NPK Phonska on most growth and yield parameters suggests that raw effluent, when applied without standardization, may introduce nutrient imbalances that hinder synergistic uptake. Variability in the nutrient concentration of catfish pond wastewater driven by feed type, stocking density, and management practices can lead to uneven availability of N, P, and K, thereby disrupting the efficiency of inorganic fertilizer absorption. This finding aligns with earlier observations by (Andriyeni et al. 2017) that untreated leachate often fails to meet the nutrient ratios required for optimal plant nutrition, despite its high total N content (1.325% on average) and P_2O_5 levels (2.645%) .

In contrast, the pronounced main effects of NPK Phonska highlight the critical importance of balanced macronutrients and sulfur for tomato development. Phosphorus's role in root system strengthening and generative processes (flower and fruit formation), potassium's contribution to stem rigidity and osmotic regulation, and sulfur's support for amino acid and enzyme synthesis collectively underpin robust vegetative growth and yield. Our results echo (Kaya et al. 2020), who demonstrated that a 15–15–15 NPK formulation significantly improved photosynthetic rates and biomass accumulation in tomato under Mediterranean conditions.

Comparatively, (Husada, 2019) reported that a 5% dilution of fish pond effluent combined with 11.25 g NPK per plant optimized all growth parameters in tomato. The discrepancy between that study and ours may stem from differences in effluent pretreatment and local soil texture, underscoring the need to standardize organic inputs before field application. Such standardization could involve sedimentation, biofiltration, or targeted dilution to achieve nutrient ratios congruent with crop demand, thereby mitigating osmotic stress or microbial imbalances. However, the positive leaf-area response in the L_1N_2 treatment indicates that low-level effluent can complement inorganic nutrients when judiciously dosed, supporting a precision nutrient-cycling framework (Zhang, Liu, and Chen 2019).

Moreover, (Rahman, Hossain, and Alam, 2022) observed up to a 40% increase in tomato fruit weight with enhanced NPK rates, corroborating our finding that 13.5 g Phonska per plant (N_2) yielded the highest early harvest weights. This consistency across agroecological zones reinforces the generalizability of precision inorganic fertilization but also highlights that benefits are most pronounced during peak nutrient demand phases early fruit set through the third harvest (Faisal and Baharuddin 2022).

Overall, these data confirm that a full-rate NPK Phonska application (13.5 g per plant) is the primary driver of early vigor, canopy expansion, fruit yield, and biomass accumulation in tomato under these field conditions. Raw catfish effluent while rich in macro- and micronutrients fails to perform as a standalone amendment, likely due to inconsistent nutrient concentrations and potential phytotoxicity. However, a modest effluent volume can transiently enhance leaf expansion when co-applied with NPK, pointing to opportunities for integrated nutrient management that reduces chemical fertilizer inputs without sacrificing performance. Future refinement should focus on standardizing effluent strength (e.g., via dilution or biofiltration) to harness its latent benefits more consistently.

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CONCLUSIONS

The findings of this study demonstrate that, under tropical field conditions, a full-rate application of NPK Phonska Plus 15-15-15 (13.5 g per plant) remains the most reliable means of achieving vigorous early canopy development, optimal fruit set, and maximal biomass accumulation in tomato. Although untreated catfish aquaculture effluent alone did not improve growth or yield likely due to its variable nutrient composition and potential osmotic stress a modest addition of 100 mL per plant, when combined with full-rate NPK, produced a transient yet meaningful enhancement in early leaf expansion. This nuance refines existing nutrient-cycling theory by identifying a narrow "synergy window" for integrating raw effluent with inorganic fertilizer in fruit-bearing solanaceous crops.

These results align with our initial aim to bridge the gap in knowledge regarding organic–inorganic nutrient interactions in tomato, confirming that balanced macronutrient supply is indispensable while also revealing conditions under which low-level organic input can complement chemical fertilizers. Looking forward, developing simple on-farm protocols such as standardized dilution or sedimentation methods to stabilize effluent nutrient ratios could expand this synergy window and mitigate risks of phytotoxicity. Moreover, long-term studies on soil health and microbial community dynamics will be essential to ensure that circular nutrient management practices remain ecologically sustainable. By valorizing aquaculture by-products and reducing reliance on synthetic inputs, our work offers a practical pathway toward sustainable intensification for smallholder farmers in tropical agroecosystems.

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