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Substitution of Mineral Fertilizers by Solid Urban Waste Compost: Tomato (*Solanum lycopersicum* L.) Productivity and Soil Fertility in Côte d'Ivoire

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Abstract | **Original Research Article**

Composting biodegradable urban solid waste offers a promising pathway to restore the fertility of degraded soils and reduce dependence on imported mineral fertilizers. Preliminary research carried out in Yamoussoukro has confirmed the agronomic potential of a solid urban waste compost for tomato cultivation in the Centre region of Côte d'Ivoire. The present research evaluates, under on-farm conditions in southwestern Côte d'Ivoire, the effects of increasing solid compost application rates (0, 10, 20, 30 $t \cdot ha^{-1}$) on the fertility of an Acrisol, tomato (*Solanum lycopersicum* L.) yield, and economic profitability, compared to an unfertilized control and a compost + NPK combination. A randomized complete block design with four replications was implemented across two sites over two consecutive growing seasons (2023–2024), with Tukey HSD post-hoc tests ($\alpha = 0.05$) and polynomial dose-response modelling. Results show consistent, significant and dose-dependent improvements in soil pH (from 5.65 to 6.15), cation exchange capacity (CEC, +64% at 30 $t \cdot ha^{-1}$), and organic matter (OM, +6.7%). Maximum fruit yield (8.22 ± 1.72 $t \cdot ha^{-1}$) was achieved at 20 $t \cdot ha^{-1}$, representing a +455% increase over the control and +226% over NPK alone. A quadratic model ($R^2 = 0.915$) estimated the economic optimum at 26.7 $t \cdot ha^{-1}$. Cost-benefit analysis confirmed the superiority of solid compost alone, with a benefit-cost ratio (BCR) of 6.15 at 20 $t \cdot ha^{-1}$ (net profit: 2,754,519 $FCFA \cdot ha^{-1}$, approximately €4,200), far exceeding the FAO threshold of 2.0. Optimized solid compost thus constitutes an effective and economically viable alternative to mineral fertilization for smallholder tomato production in Côte d'Ivoire.
Keywords: Co-composting; Acrisols; tomato; profitability; Côte d'Ivoire.

1. INTRODUCTION

The Ivorian agricultural sector accounts for approximately 22% of gross domestic product and forms the foundation of national food security. It faces growing structural challenges: the gradual degradation of soil resources, excessive use of chemical inputs, and insufficient adoption of sustainable production systems (Koffi, 2023). In the central part of the country, the Yamoussoukro region is home to a thriving market gardening sector (Akotto *et al.,* 2022), focused primarily on tomatoes (Solanum lycopersicum L.), a high-value-added food and cash crop whose economic importance for urban and peri-urban households is widely recognized (Akotto *et al.,* 2020). However, this production relies on the widespread and uncontrolled use of pesticides and mineral fertilizers, which, although beneficial to yields in the short term, lead to a gradual deterioration of the soil's physical and chemical properties and pose serious risks to the environment and public health (Assoh *et al.,* 2025).

At the same time, the city of Yamoussoukro is generating increasing amounts of biodegradable municipal solid waste (garden and kitchen waste, poultry manure, vegetable peelings, and fruit scraps). The agronomic recovery of this waste through composting is part of a circular economy approach (Assoh *et al.,* 2025; Zongo *et al.,* 2025), transforming urban waste into a fertilizing resource, in line with the sustainable development goals of the 2030 Agenda (Koffi, 2023).

Several studies have shown that incorporating composted organic residues improves soil properties (Tshala *et al.,* 2019; Zongo *et al.,* 2025; Assoh *et al.,* 2025). However, the agronomic effectiveness of these products depends on their intrinsic quality and the rates applied under actual growing conditions (Kane *et al.,* 2025).

Based on a preliminary study conducted under semi-controlled conditions in Yamoussoukro by Akotto *et al.,* (2022) on three compost formulations with varying urban waste ratios the recommended dose (TR1: 862.5 kg of solid compost/ha), half the recommended dose (TR½: 431.25 kg of solid compost/ha), and 10 times the recommended dose (TR10: 8,625 kg of solid compost/ha) This research demonstrated the agronomic effectiveness of the composts and identified the solid compost TR1 as a product of interest, combining effective sanitization, carbon stabilization, and satisfactory nutritional balance. It has also been shown to be effective in improving the growth and yield parameters of tomatoes (Solanum lycopersicum L.) in Toumbokro.

While this study confirmed the quality of the compost produced from a mixture of water hyacinth, cassava peelings, poultry manure, cashew shells, and citrus residues, and validated the recommended application rate (862.5 kg ha^{-1}), its impact on the fertility of acidic Acrisols and its economic viability under smallholder conditions in southwestern Côte d'Ivoire remain insufficiently documented.

Against the backdrop of rising costs for mineral fertilizers and the search for sustainable alternatives, this study aims to: first, evaluate the effects of four TR1 application rates (0, 10, 20, and 30 t ha^{-1}) on soil chemical fertility and the productivity of S. lycopersicum in smallholder farming systems; second, compare its economic profitability to that of conventional mineral fertilization (NPK 15-15-15); and third, determine whether TR1 constitutes a technically effective and economically viable option under the soil and climate conditions of the forested southwest of Côte d'Ivoire.

2. MATERIALS AND METHODS

2.1. Study Sites and Soil Characterization

The study was conducted at two agricultural sites located 5 km apart in Goréké (5° 1′ 15″ N and 6° 46′ 45″ W), in the San Pedro (SP) region, 348 km southwest of Abidjan. SP is home to the country's second-largest port, the world's leading port for cocoa exports (Awal *et al.,* 2021).

Soil characterization (2x2 representative profiles) revealed an endopetroplinthic Acrisol (IUSS Working Group WRB, 2022). In the 0–20 cm layer, the soil has a sandy-loamy texture (Djiha *et al.,* 2026), an acidic pH (soil pH = 4.37), an organic matter (OM) content of 1.21%, and a C/N ratio of 13.44, as well as a low CEC (1.98 $cmol^+$/kg), with exchangeable base contents of 0.63 (Ca^{2+}), 0.37 (Mg^{2+}), 0.41 (K^+), and 0.09 (Na^+) $cmol^+$/kg (base saturation of 75.8%), consistent with the definition of Acrisols. The total carbon (7040 mg kg^{-1}) and total nitrogen (524 mg kg^{-1}) contents indicate modest chemical fertility, typical of soils under continuous cropping without organic matter addition. These characteristics justify the use of an organic soil amendment (TR1).

2.2. Composting Process and Characterization of the Solid Compost of Interest

Composting was carried out using the surface windrow method (Kitabala *et al.,* 2016). The composting process took 30 days, with the windrows being turned and watered. The swath is a square with sides measuring 1.5 m, for a total area of 2.25 m^2. After sorting and sifting, weigh out 10 buckets of organic matter (3 to 4 kg each) and spread them over the windrow to a depth of 20 cm. Then add 2.5 watering cans (about 27.5 liters of water) to form the first layer. The same process is repeated for the second layer. Starting with the seventh layer, ten watering cans are added, and the same applies to the eighth. Once assembled, the windrow is 160 cm high. The windrow is then covered to prevent excessive evaporation. The temperature is checked and recorded every day, as is the humidity. The compost is turned weekly to release trapped gases and aerate the mixture to oxygenate it.

The physicochemical characterization of the solid compost in question reveals an organic soil amendment of high agronomic value: : total nitrogen content of 2.4% SM (> standard 1–2% DM), organic matter of 41.5% MS (within the standard range), particularly high available calcium (Ca^{2+} = 3.8% MS), which provides a beneficial liming effect on acidic Acrisols, and satisfactory levels of P_2O_5 (0.7% MS) and Mg^{2+} (0.5% MS). Combined with effective sanitization (≥ 65 °C), carbon sequestration (+284%), and an optimal nutritional balance (C/N = 11.32). This formulation confirms the product's compliance with the relevant agronomic standards (NFU 44-051) and justifies its selection as a substitute for mineral fertilizers at the recommended TR1 rate (862.5 kg ha^{-1}), which is the subject of this study.

2.3. Experimental setup and cultivation procedures

A randomized complete-block design with four replicates was implemented at each site (six replicates) per treatment: T0 = control treatment with no fertilizer (0 t ha^{-1}); T10 (10 t ha^{-1}), T20 (20 t ha^{-1}), T30 (30 t ha^{-1}), T-NPK 15-15-15 (250 kg NPK ha^{-1}) as the mineral reference. The individual plots measured 6.4 × 6 m (36.4

m²), with a 1-meter border between plots and a 2-meter border between blocks. The solid compost was spread by hand 15 days before sowing and worked into the soil to a depth of 10–15 cm.

The 'Cobra 26 F1 Hybrid' tomato variety (Technisem, Ivory Coast) was selected for its agronomic performance, which is well-suited to local climatic conditions: robust growth, high productivity (15 t/ha in the dry season; 20 t/ha in the rainy season), and resistance to bacterial wilt (Ralstonia solanacearum). The seedlings were sown in a cell tray 21 days before transplanting. The seedlings were transplanted at a spacing of 80 × 40 cm (density: 31,250 plants per hectare) and thinned to 2 plants per hole 15 days after emergence. Crop management practices (weeding, hilling) followed local farming methods, without irrigation or additional pesticide use.

2.4. Soil tests and agronomic calculations

The chemical and physical properties of the soil were determined using composite samples (0–20 cm) collected before the application of treatments and after harvest. The parameters analyzed included: pH (1:2.5), organic carbon (Walkley-Black method), organic matter (OM = OC × 1.724), total nitrogen (Kjeldahl), available phosphorus (colorimetry), exchangeable cations (K, Ca, Mg) by flame photometry, cation exchange capacity (CEC) using ammonium acetate, as well as bulk density. The relative changes (Δ) were calculated according to Kaho *et al.,* (2011):

Δ (%) = $100 \times (X_2 - X_1) / X_1$ (1), where X_1 and X_2 represent the initial and final values of the parameter in question, respectively.

The apparent utilization coefficient (AUC) of the compost was estimated using the following equation:
AUC (%) = [(Yield after treatment – Yield at T0) / Application rate] × 100 (2).

Fruit yield was determined by weighing the fruit on a plot-scale scale after sorting out the healthy fruit, and then extrapolated to a per-hectare basis.

2.5. Statistical and Economic Analyses

A two-way ANOVA (Dose × Season) was performed after verifying the normality of the residuals (Shapiro-Wilk test) and the homogeneity of variances (Levene's test). Multiple comparisons were performed using Tukey's HSD test ($\alpha = 0.05$). Linear and polynomial (second-degree) regressions were fitted to the dose-response relationships. The chemical fertility index (CFI) was calculated as the standardized average of the variations in pH, organic matter (OM), N, P, K, Ca, Mg, and cation exchange capacity (CEC). The benefit-cost (B/C) analysis included input costs (solid compost: 21,000 CFA francs ha^{-1}; NPK: 250,000 CFA francs ha^{-1}) and the value of production (400 CFA francs per kilogram of fresh tomatoes). The B/C ratio = (Production value – Expenses) / Expenses (3); the FAO acceptability threshold is B/C ≥ 2.0 (Kelly and Murekezi, 2000). All analyses were performed using R 4.5.3 (R Core Team, 2025).

3. RESULTS

3.1. Effects on the physicochemical properties of the soil

The application of solid compost significantly improved all soil chemical properties in a dose-dependent manner (Table 1). TR1 increases the pH from 5.65 (T0) to 6.15 (T20), the organic matter content from 12.23 to 13.05 g kg^{-1} at 30 t ha^{-1} (+6.7%), and the cation exchange capacity by 63.9% at 30 t ha^{-1}. The gains in major nutrients are substantial: Total N (+27% to 30 t/ha), available P (+36%), exchangeable K (+91%), exchangeable Ca (+62%), and exchangeable Mg (+59%). The bulk density decreases from 1.50 to 1.38 g/cm³. The chemical fertility index (ΔIFC) follows a quadratic relationship with dose
($y = 0.00x + 0.0001x^2$; $R^2 = 0.525$).

The CAU reaches its maximum at 20 t/ha (4.93%), indicating that it has reached its optimal efficiency, while it becomes negative at 30 t/ha (-4.08%). These observations indicate partial saturation, with potential losses due to leaching (Fig. 1).

Table 1: Effects of solid compost application rates on soil physicochemical properties (mean ± standard deviation, 2 trials, n = 4). T0: control treatment (0 t ha⁻¹); T10: 10 t ha⁻¹ of solid compost; T20: 20 t ha⁻¹ of solid compost; T30: 30 t ha⁻¹ of solid compost; CEC: cation exchange capacity; ΔIFC: change in the chemical fertility index; CAU: apparent utilization coefficient

Property / Indicator	Unit	T0	T10	T20	T30
pH	-	5,65±0,04	5,78±0,17	**6,15±0,04**	5,95±0,15
C organic	g kg^{-1}	7,10±0,11	7,38±0,18	7,54±0,13	7,57±0,17
Organic matter	g kg^{-1}	12,23±0,04	12,73±0,36	12,93±0,13	13,05±0,31
Total N	g kg^{-1}	0,52±0,01	0,60±0,04	0,64±0,02	0,66±0,03
Absorbable P	mg kg^{-1}	1,44±0,13	1,57±0,15	1,82±0,10	1,96±0,09
K interchangeable	cmol kg^{-1}	0,33±0,03	0,44±0,07	0,58±0,07	0,63±0,06
Ca Exchangeable	cmol kg^{-1}	1,26±0,08	1,70±0,13	1,84±0,16	2,04±0,18
Exchangeable Mg	cmol kg^{-1}	0,75±0,06	0,91±0,13	1,03±0,14	1,19±0,12
CEC	cmol kg^{-1}	2,52±0,18	3,07±0,28	3,83±0,46	4,13±0,31
Bulk density	g cm^{-3}	1,50±0,03	1,46±0,04	1,39±0,03	1,38±0,03
ΔIFC	-	0,17±0,07	0,26±0,08	0,28±0,06	0,37±0,13
Humic balance	t ha^{-1}	-1,12±0,22	0,12±0,75	0,72±0,85	-1,94±1,03
CAU (%)	%	-	0,94	**4,93**	-4,08

The values in bold indicate the optimal dose.

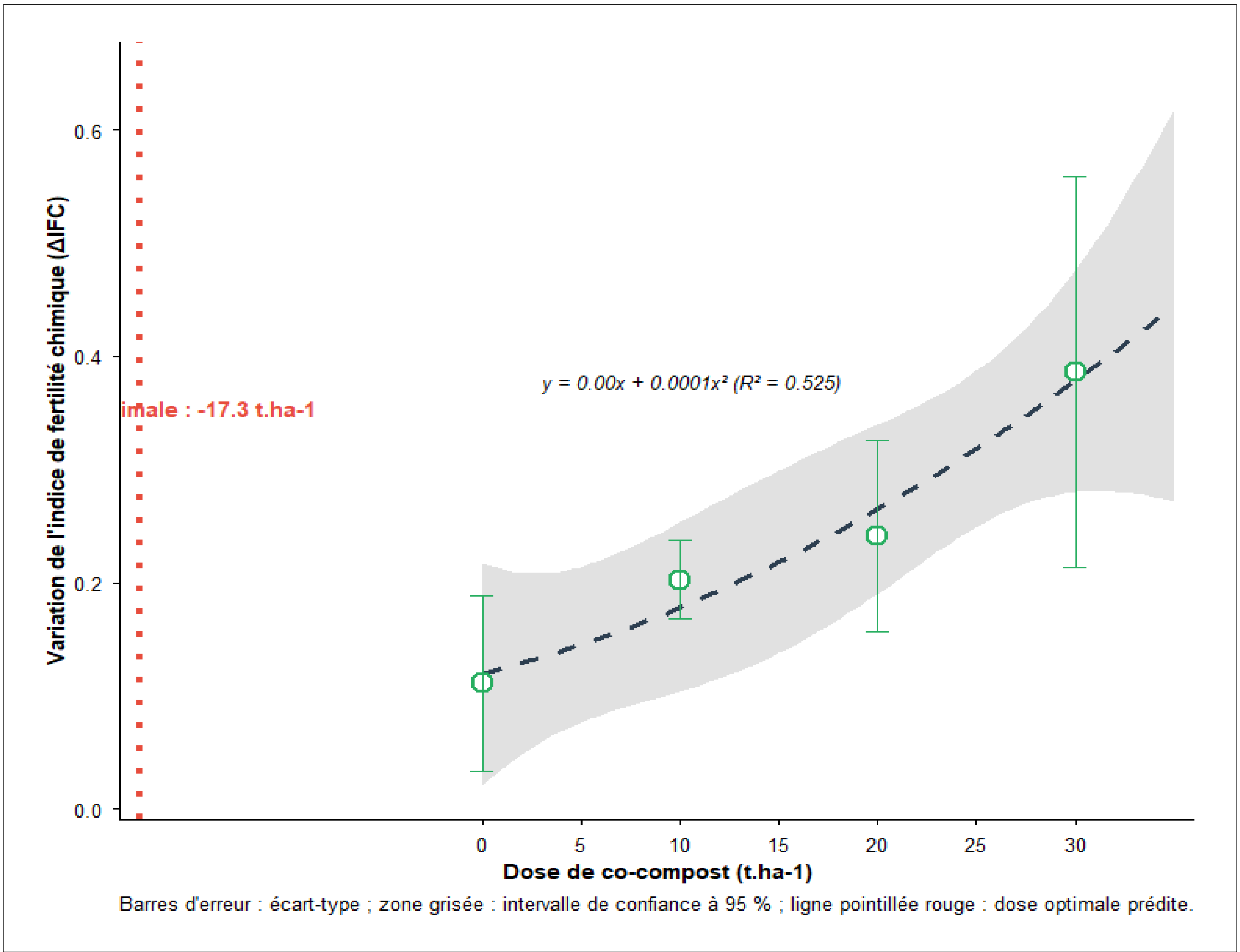

Fig. 1: Dose-response relationship between solid compost rate and the variation of the chemical fertility index (ΔIFC). ΔIFC: variation in chemical fertility index; R²: coefficient of determination

Points are observed means per dose with error bars = standard deviation (n = 4). The solid line and grey area represent the quadratic regression model and its 95% confidence interval, respectively. The red dashed line indicates the estimated optimal rate (-17.3 t ha^{-1}; negative value reflecting a model limitation).

3.2. Fruit Yield and Dose-Dependent Modeling

Analysis of the quadratic response of fruit yield to solid compost application rates (Table 2) shows an absolute maximum of 8.22 ± 1.72 t/ha at 20 t/ha, representing a 455% increase compared to T0, a 226% increase compared to T-NPK, and a 134% increase compared to T10. The rate of 30 t/ha results in a drop in yield to 5.26 ± 0.91 t/ha.

Table 2: Economic indicators by treatment (averages from the two growing seasons). Economic indicators by treatment (averages from the two growing seasons). The values in bold are the highest. T0: control treatment without fertilization (0 t ha⁻¹); T10: 10 t ha⁻¹ of solid compost; T20: 20 t ha⁻¹ of solid compost; T30: 30 t ha⁻¹ of solid compost; T-NPK: 15-15-15 NPK treatment (250 kg ha⁻¹); B/C: benefit-to-cost ratio; FCFA: CFA franc (1 € = 655.96 FCFA). Assumptions: price of fresh tomatoes = 400 CFA francs/kg (≈0.61 €/kg); cost of solid compost = 21,000 CFA francs/t (≈32 €/t, including production, transport, and application); NPK = 250,000 FCFA ha⁻¹ (≈381 € ha⁻¹). FAO break-even point: B/C ≥ 2.0

Indicateur	Unit	T0	T10	T20	T30	T-NPK
Yield	T ha^{-1}	1,48±0,23	3,51±0,64	**8,22±1,72**	5,26±0,91	2,52±0,12
Gross output	FCFA ha^{-1}	593 172	1 402 798	**3 288 967**	2 102 819	1 007 336
Input costs	FCFA ha^{-1}	0	210000	370000	530000	530000
Net income	FCFA ha^{-1}	563513	1122658	**2754519**	1467678	426969
B/C ratio	-	-	5,01	**6,15**	3,31	1,74

The values in bold are the highest. B/C = Benefit/Cost

Fig. 2 confirms the nonlinear response to solid compost application rates, with a fitted polynomial regression of yield ($R^2 = 0.915$):

Yield (t/ha) = -0.422 + 0.897 × Dose - 0.0168 × Dose². It identifies an agronomic optimum of 26.7 t/ha. Given the similarity in yields (20 and 27 t/ha) and the operational simplicity it offers, a fruit yield of 20 t/ha is considered the practical optimum.

3.3. Economic profitability and comparison of fertilization strategies

An analysis of the B/C ratio (Table 2) reveals that solid compost alone is significantly more cost-effective than all other strategies tested. The rate of 20 t/ha yields the maximum net profit (2,754,519 CFA francs/ha, approximately €4,200/ha), with the highest B/C ratio (6.15), exceeding the control (563,513 FCFA/ha, or €859/ha) by 389% and the NPK strategy (426,969 FCFA/ha, or €651/ha) by 545%. The 10 t/ha application rate remains very attractive (B/C = 5.01) and is the first-choice option for growers with limited capital.

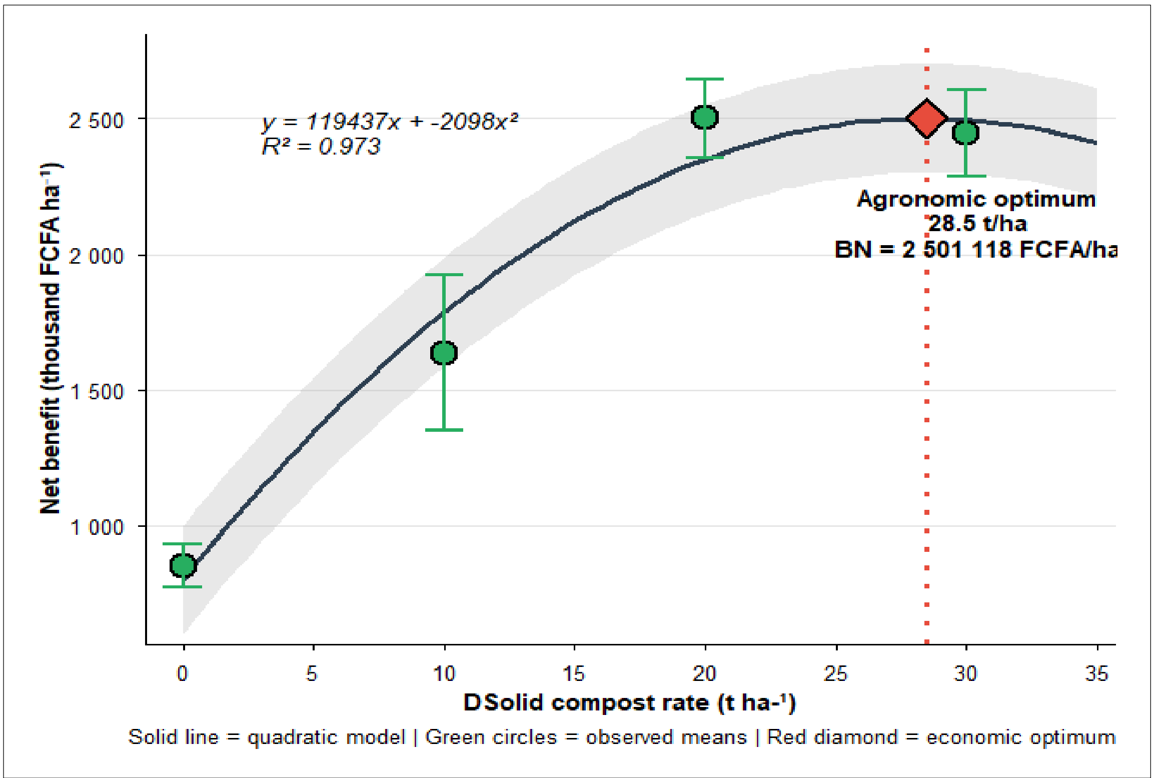

Fig. 2: Net dose-benefit relationship of solid compost modeled using quadratic regression (compost-only strategy, averages from 2 campaigns, 2 sites)

R^2: coefficient of determination. The green points represent the average net profits (NP) observed per dose, with error bars corresponding to the standard deviation. The solid line and the shaded area represent the quadratic model and its 95% confidence interval. The red diamond indicates the estimated optimal economic rate (26.7 t/ha; BN = 2,529,244 CFA francs/ha). The model equation and the coefficient of determination (R^2) are shown in the graph.

Contrary to expectations, the combination of solid compost and NPK does not improve profitability: The B/C ratio for T-NPK (1.74) is below the FAO break-even threshold of 2.0 (Fig. 3), whereas all applications of solid compost alone far exceed it (5.01 to 6.15). The cost of adding NPK (250,000 CFA francs per hectare / €381 in additional expenses) is not offset by the resulting increase in yield.

These results thus support the hypothesis that mineral fertilizers can be completely replaced by solid compost made from municipal solid waste and green waste. The quadratic model (Fig. 2; $R^2 = 0.915$) confirms an economic optimum of 26.7 t/ha (2,529,244 CFA francs/ha, or €3,855/ha), consistent with the agronomic optimum.

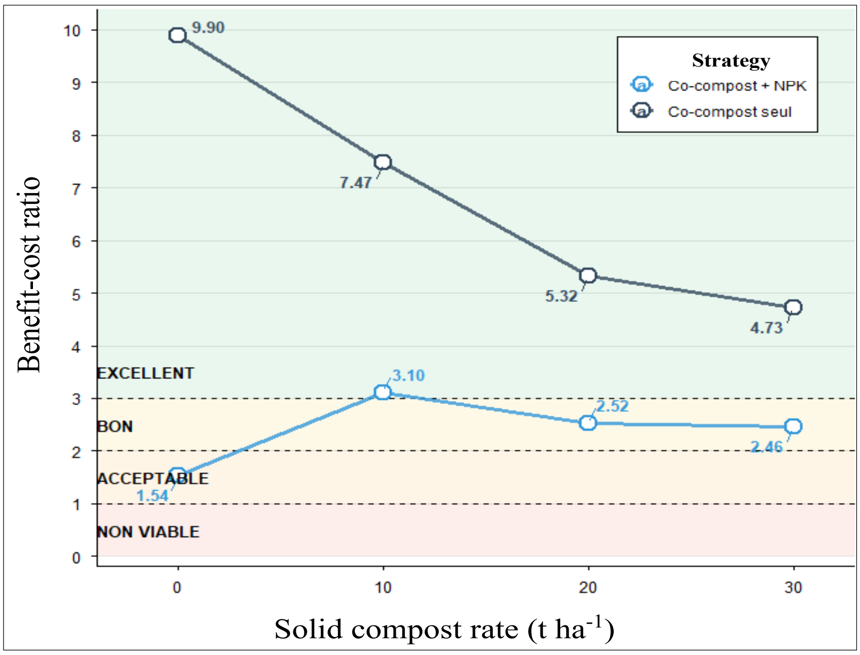

Fig. 3: Benefit-to-cost ratio (B/C) by solid compost dose and fertilization strategy

Colored zones: red = not viable (B/C < 1); yellow = acceptable (1 ≤ B/C < 2); green = good to excellent (B/C ≥ 2). Dashed line: FAO profitability threshold (B/C = 2.0).

The risk-return matrix (Fig. 4) ranks the strategies based on their coefficient of variation (CV) and their B/C ratio. The solid compost application rates (10, 20, 30 t ha⁻¹) all fall within the optimal range (CV < 30%, B/C ratio > 2.0), with a decreasing risk as the application rate increases. The solid compost + NPK treatments fall within the acceptable to improvable range, due to greater variability across sites. The T-NPK test alone falls within the "avoid" zone (CV > 40%, B/C ratio < 2.0). These observations demonstrate the instability and low profitability of using mineral fertilizers exclusively under the soil and climate conditions of the study site.

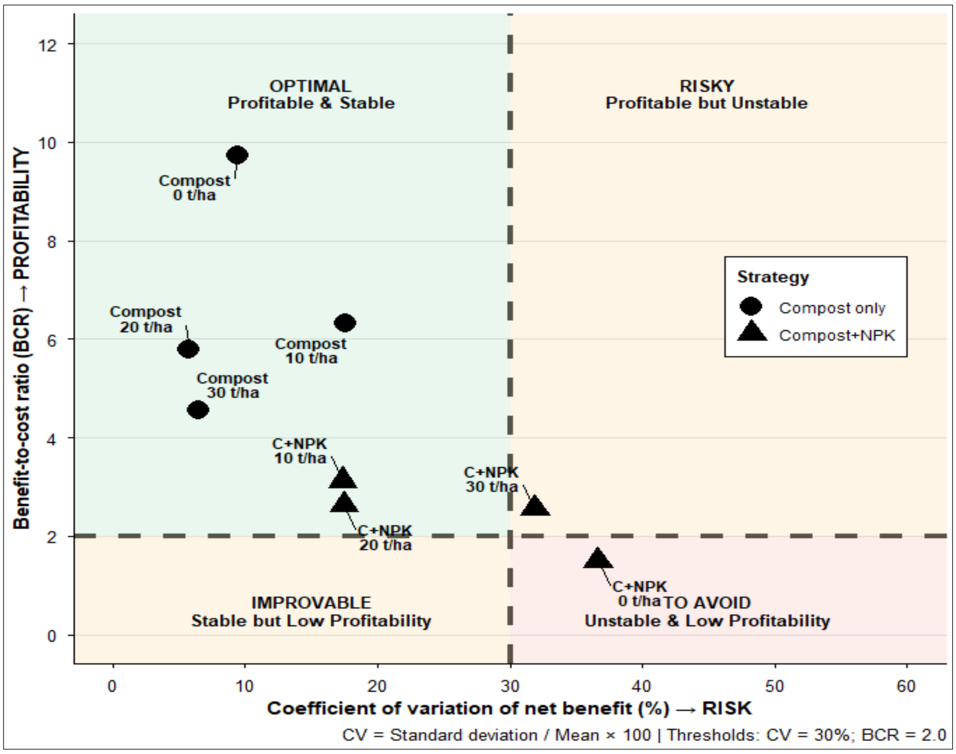

Fig. 4: Risk-profitability matrix of fertilization strategies (means over 2 seasons and 2 sites). x-axis: coefficient of variation (CV, %) of net benefit across sites and seasons (economic risk indicator); y-axis: benefit-to-cost ratio (B/C, profitability indicator). Circles: compost-only strategy (T10, T20, T30); triangles: compost + NPK strategy; thresholds: CV = 30% and B/C = 2.0 (FAO threshold). CV: coefficient of variation; B/C: benefit-to-cost ratio; NPK: mineral fertilizer NPK 15-15-15 (250 kg ha⁻¹)

4. DISCUSSION

4.1. Improving soil fertility with solid compost

The liming effect of solid compost helped neutralize the acidity of Acrisol, improving phosphorus availability and reducing aluminum toxicity (Tshala *et al.,* 2019).

The increase in CEC (+64%) exceeds the gains reported by Sana *et al.,* (2025) for composts made exclusively from plant material (+15–30%). This effect is due to the nature of municipal waste, which is rich in exchangeable bases and microbial polymers that promote the formation of stable organo-mineral complexes, thereby providing long-term reinforcement to the soil's absorbent structure.

The positive humic balance recorded at the T10 (+0.12) and T20 (+0.72 t ha^{-1}) treatment levels confirms carbon sequestration, while the negative balance at T30 (-1.94 t ha^{-1}) suggests accelerated mineralization at high application rates, consistent with the negative CAU observed, in line with the findings of Essy *et al.,* (2022).

4.2. Tomato Yield Response to Compost Application Rates and Mechanisms

The decrease in tomato yield observed at T30 contrasts with the linear response reported by Azangue *et al.,* (2019) for household composts. This discrepancy can be explained by the rapid release of nitrogen from high-dose poultry manure (T30), leading to a mismatch between nitrogen availability and the critical stages of tomato growth (flowering, fruit set). A similar phenomenon has been described in the context of high manure application rates, where yield-reducing effects have been observed (Lompo *et al.,* 2009; Pouya *et al.,* 2022).

The highest yield recorded (8.22 t ha^{-1}), achieved without supplemental mineral fertilization, exceeds the 5.71 t ha^{-1} reported by Kouassi *et al.,* (2024) under a combined application of natural phosphate (NP) and triple superphosphate (TSP).

These results build on the preliminary work conducted by Akotto *et al.,* (2022) in Yamoussoukro, while extending it to a distinct agroecological zone (acidic acrisol of the forested southwest) and higher application rates, thereby enabling the identification of a robust economic optimum. Conversely, Kouassi *et al.,* (2024), in the savanna region of central Côte d'Ivoire, focused on phosphorus management using PN/TSP ratios, which had a positive effect on pH due to the gradual solubilization of natural phosphate.

4.3. Replacing mineral fertilizers with solid compost: economic efficiency

The economic superiority of solid compost applied alone (B/C = 5.01–6.15) compared to the combination of solid compost and NPK fertilizer (B/C = 1.74) contrasts with the traditional model of integrated organic-mineral fertilization described by Lompo *et al.,* (2009). This difference can be explained by the nature of solid compost: an optimal C/N ratio ensures a gradual release of nutrients, a substantial supply of bioavailable phosphorus, and a pH-correcting effect.

These findings have significant strategic implications. Recycling solid biodegradable municipal waste is an integrated approach that will simultaneously reduce urban sanitation costs, dependence on imported mineral fertilizers, and the gradual degradation of peri-urban soils (Amakpe *et al.,* 2023).

5. CONCLUSION

This study demonstrates that, under smallholder conditions in southwestern Côte d'Ivoire, a solid compost made from biodegradable urban waste can replace NPK mineral fertilizers on degraded acidic Acrisols, with superior performance. The key achievements are: improved soil fertility (CEC, pH, CAU), an optimal yield of 8.22 t/ha, and a high B/C ratio. The rate of 20 t/ha is the optimal level from a technical and economic standpoint, while 10 t/ha remains cost-effective for farms with limited resources. These findings support the integration of urban wastewater systems into strategies for the restoration of peri-urban soils, balancing environmental services with food security. However, long-term studies that include monitoring of micropollutants and health assessments are needed to support these recommendations.

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