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Partial substitution of chemical fertilizer with microbial organic fertilizer improves soil properties, yield and quality of tomato

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Abstract: The partial substitution of chemical fertilizer with microbial organic fertilizer (OF) may be more beneficial and sustainable in crop production. This study aimed to examine the rate of partial substitution of chemical fertilizer (CF) with microbial OF that could improve soil chemical properties and maintain high fruit yield and quality in tomato, and to determine the extent of contribution of the agronomic traits to fruit yield in tomato. The experiments were conducted in the field from February to June in 2020 and 2021 and arranged in RCBD with four treatments: 100% chemical fertilizer (control) and 25, 50 and 75% substitution of CF with microbial OF. The agronomic parameters such as plant height, leaf number, shoot dry weight and fruit yield as well as fruit quality were measured .The results showed that partial substitution of CF with microbial OF significantly promoted plant growth and fruit yield and improved fruit quality in tomato via the improvement of soil chemical properties. The 25% substitution of CF with microbial OF could be optimal for tomato production in Hung Yen province, Vietnam which has the fluvisol and loam soil. Furthermore, the tomato fruit yield was greatly influenced by the number of fruits per plant (r^2 =0.89), fruit weight (r^2 =0.49) and the shoot dry weight (r^2 = 0.40). The changes in these three agronomic traits collectively contributed to 95% changes in the tomato yield. The present findings suggested that farmer can substitute CF with 25% microbial OF and focus more on increasing the number of fruits per plant to optimize fruit yield in tomato.

Keywords: tomato; microbial organic fertilizer; fruit yield and quality; correlation and regression model.
Abbreviations: CF_chemical fertilizer; OF_organic fertilizer; SDW_shoot dry weight; NoFT_number of fruit trusses; NoFpT_number of fruits per truss; NoFpP_number of fruits per plant; AFW_average fruit weight; FWpP_fruit weight per plant.

Introduction

Tomato is one of the most important vegetable crops in the world due to its high economic benefits and nutritional value. Tomato fruits are a good source of vitamins, lycopene, minerals, proteins, and other essential health-related compounds and can be consumed as fresh and processed products. The total area planted to tomato is around 4.8 million ha worldwide, with a total production output of 201 million tons based on the average yield of 41.5 tons ha^{-1} (FAOSTAT, 2018). In 2019, the total area planted to tomato in Vietnam's tomato was around 24 thousand ha, with a total production output of 673.2 tons, based on an average yield of 28.3 tons ha^{-1} (Doan et al., 2021), which is lower compared to the world average. The observed low yield of tomato in Vietnam can be attributed to a combination of the use of low-yielding varieties, low and/or poor fertilization, erratic weather conditions, inadequate irrigation, pests and diseases and, etc. Among these concerns, improved fertilizer management could be one of the options to improve tomato production (Saha et al., 2019).

Farmers normally relied mainly on CF to achieve maximum yield. However, the long-term use of high-dose CF can adversely affect the properties of soil, leading to an increase in soil hardness and acidification, and reduced soil organic matter, and soil fertility decline over time (Lv et al., 2020). Most of the CF applied in the soil are not absorbed and utilized by crops. A portion of this applied CF will be emitted to the atmosphere or leaked to water sources, which was estimated to 50% in N and 90% of P applied, is lost (Simpson et al., 2011). Excessive use of CF application also causes concerns about food safety and quality, and environmental hazards (Ye et al., 2020). Therefore, the maintenance of high and stable crop yield through a balanced and efficient management of CF, is critical in achieving sustainable crop production (Lu et al., 2023).

The use of OF improves the physical and chemical characteristics of soil, such as structure, water storage capacity, and nutrients, and the yield and quality of crops, and reduces the risks of ecological environment deterioration (Qui et al., 2021). But heavy reliance on OF do not always meet the timely nutrient demand of crops because of its slow-release characteristic and low nutrient content compared with CF (Xiao et al., 2017). To improve climate change adaptation, reduce greenhouse gas emissions, and create safe agricultural products, the Vietnamese Ministry of Agriculture and Rural Development Affairs released a policy in 2023 targeting that 30% of the area must be cultivated using organic fertilizers by 2030 and 50% by 2050. Hence, this policy needs supporting research to identify the optimum balance between CF and OF for crop production.

The partial substitution of CF with OF in vegetable production improves the yield and quality and enhances the soil quality (Yi et al., 2021; Lu et al., 2023) as found also in wheat and maize (Lv et al., 2023), and in tomato (Islam et al., 2017; Hashimi and Habibi, 2021; Wu et al., 2022). Several studies on the partial substitution of CF with organic manure or compost have been done on tomato, but studies on the use of microbial OF is still limited, especially in Vietnam. We hypothesized that microbial OF combined with a reduced rate of CF could produce yield and fruit quality of tomato comparable to those applied with full

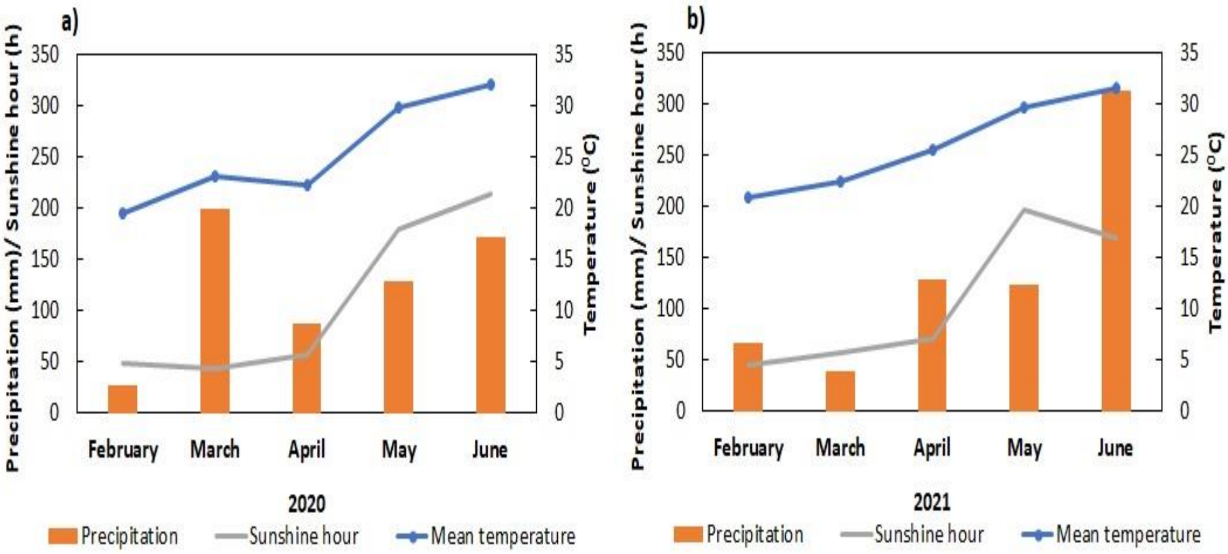

Figure 1. Meteorolofical conditions of the experimental site during the experiment periods in (a) 2020 and (b) 2021.

rates of CF. Some of the soil chemical properties, such as organic matter, available N, P and K will also be improved with partial substitution of CF with microbial OF in continuous cropping. Thus, this study aimed to (1) examine how much substitution of CF with microbial OF would improve soil chemical properties and consequently maintain high fruit yield and quality in tomato, and (2) determine the extent of contribution of agronomic traits to fruit yield of tomato when applied with CF partially substituted with microbial OF.

Results and discussion

The substitution of chemical fertilizer with microbial organic fertilizer improved the soil chemical properties

The combined application of OF and CF or partial replacement of CF with OF enhanced the soil chemical properties and consequently increased fruit yield and quality in tomato (Islam et al., 2017; Khan et al., 2017; Ye et al., 2020, Wu et al., 2022). In this study, the ANOVA revealed no significant interaction between fertilizer treatment and year on all the parameters measured (Table 2). The fertilizer treatment had a significant effect on the soil chemical properties except pH while the year had a significant effect on soil organic matter content and available N (Table 2). The long-term application of OF can improve soil microbial biomass and enzyme activity, and enhance soil organic matter content and quality (Bending et al., 2004)

The pH value is a crucial factor affecting nutrient uptake and utilization by plants. In the current study, the substitution of CF with microbial OF tended to increase soil pH relative to 100% CF (Figure 2). The results of the global meta-analysis showed that in acidic soil (pH < 6), the application of OF can increase pH, while in neutral soil (pH = 6~8), it can increase soil pH although the magnitude of increase is generally smaller than in acidic soil (Fan et al., 2023). The OFs are known to regulate soil acidity due to their alkaline nature (Wu et al., 2022).

Similarly, the partial substitution of CF with microbial OF increased soil organic matter, with a significant effect achieved in CF with 75% OF substitution level in both years. The available N and P increased with the increase in the rate of substitution of CF with microbial OF in 2021 only. In 2021, the available N was significantly higher in CF_{50} + OF_{50} and CF_{25} + OF_{75}, while available P exhibited a significant increase only in CF_{25} + OF_{75}, compared with CF_{100}. The available K showed a similar pattern with that of the soil organic matter, but the increase was significantly higher only in CF_{50} + OF_{50} and CF_{25} + OF_{75} compared to CF_{100} in both years (Figure 2). Previous studies have reported that the partial substitution of CF by organic compounds, manure or compost can enhance the accumulation of the soil organic matter via the improvement in soil microbial activity (Khan et al., 2017; Lu et al., 2023; Fan et al., 2023), which enhanced the availability of N, P, and K in the soil (Khan et al., 2017; Hashimi and Habibi, 2021; Fan et al., 2023).

In this study, the partial substitution of CF with microbial OF improved the soil properties since microbial OF contains N-fixing microorganism, phosphate solubilizing microorganisms and cellulose-degrading microorganisms. Nitrogen-fixing microorganisms produce nitrogenase, which transforms atmospheric N_2 into ammonia for plant use, while phosphate solubilizing microorganisms convert P from insoluble inorganic to soluble organic form, which important for metabolism and development of an organisms. Microbial OFs significantly improve the richness and variety of soil microorganisms, which is crucial for maintaining soil microecological balance and improving soil quality (Wei et al., 2024). Liu et al. (2024) reported that microbial OF improves photosynthesis rate, stomatal conductance of leaves, and more developed root systems, ultimately promoting plant growth of tomato. In this study, the partial substitution of CF by microbial OF enhanced soil fertility (Figure 2), promoted the growth and development (Figure 3), and consequently increase fruit yield and quality of tomato (Figure 4 and Figure 6).

The substitution of chemical fertilizer with microbial organic fertilizer improved the growth and development of tomato

Plant height is a growth indicator of tomato, which can be affected by variety and external factors such as nutrition (Saha et al., 2019). In this study, fertilizer treatments had a significant effect on plant height of tomato in both years. The CF_{75} + OF_{25} had the tallest plant height, while CF_{25} + OF_{75} had the shortest. Compared to CF_{100}, CF_{75} + OF_{25} tended to have taller plants in both years (Figure 3a). Islam et al. (2017) and Saha et al. (2019) showed that partial substitution of CF with OF improved plant height relative to 100% CF. In contrast, the number of leaves per plant was not significantly affected by fertilizer treatment (Figure 3b), similar to those reported by Buajaila et al. (2022) which may be largely dependent on genetic factors linked to cultivars (Buajaila et al., 2022).

The shoot dry weight (SDW) is a direct indicator of plant's vegetative growth. In this study, SDW was positively and significantly influenced by plant height ($r = 0.65^{**}$) and number of leaves ($r = 0.40^{*}$) (Table 3). Similarly, SDW was affected by partial substitution of CF by OF. The SDW in CF_{75} + OF_{25} was greater than in CF_{100} (Figure 3c) similar to the results of Zhai et al. (2022) which showed that partial substitution of CF by OF increased dry matter accumulation and yield. Sanam et al. (2022) also reported that any improvement on the growth parameters should contribute to the enhancement in fruit yield of tomato. In this study, the SDW accounts for more than 40% of fruit yield (Figure 5c) indicating that other traits are also contributing to the increase of fruit yield in tomato.

Table 2. ANOVA results for soil properties and growth characters, fruit yield components, fruit yield and quality of tomato.

Source of variation	pH	OM	N	P	K	PH	NoL	SDW	
Treatment	ns	***	*	*	***	**	ns	***	
Year	ns	*	*	ns	ns	**	ns	*	
Treatment x Year	ns	ns	ns	ns	ns	ns	ns	ns	
Source of variation	NoFT	NoFpT	NoFpP	AFW	FY	VitC	Pro	TS	NC
Treatment	ns	***	***	**	***	***	**	***	***
Year	ns	ns	ns	ns	ns	ns	ns	ns	ns
Treatment x Year	ns	ns	ns	ns	ns	ns	ns	ns	ns

ns, *, ** and *** mean not significant, significant at $P < 0.05$, 0.01 and 0.001, respectively.
pH: pH value, OM: organic matter, N: available N, P: available P_2O_5, K: available K_2O, PH: plant height, NoL: Number of leaves, SDW: shoot dry weight, NoFT: Number of fruit trusses, NoFpT: Number of fruits per truss, NoFpP: number of fruits per plant, AFW: average fruit weight, FY: fruit yield, VitC: vitamin C, Pro: protein, TS: total sugar, NC: nitrate accumulation.

Table 3. Pearson correlations of fruit yield per plant and growth parameters and yield components as affected partial substitution of chemical fertilizer with microbial organic fertilizer

Property	PH	NoL	SDW	NoFT	NoFpT	NoFpP	AFW	FWpP
PH	1							
NoL	0.42^{*}	1						
SDW	0.65^{**}	0.40^{*}	1					
NoFT	0.03^{ns}	0.25^{**}	0.02^{ns}	1				
NoFpT	0.50^{**}	0.18^{ns}	0.53^{**}	-0.27^{*}	1			
NoFpP	0.53^{**}	0.33^{**}	0.59^{**}	0.05^{ns}	0.86^{**}	1		
AFW	0.34^{**}	0.20^{*}	0.44^{**}	0.02^{ns}	0.42^{**}	0.43^{**}	1	
FWpP	0.55^{*}	0.34^{**}	0.63^{**}	0.018^{ns}	0.83^{**}	0.94^{**}	0.70^{**}	1

ns, * and ** mean not significant, significant at $P < 0.05$ and < 0.01, respectively. PH: plant height (cm), NoL: number of leaves (leaves $plant^{-1}$), SDW: shoot dry weight (g $plant^{-1}$), NoFT: Number of fruit trusses (truss $plant^{-1}$), NoFpT: Number of fruits per truss (fruit $truss^{-1}$), NoFpP: number of fruits per plant (fruits $plant^{-1}$), AFW: average fruit weight (g $fruit^{-1}$), FWpP: fruit weight per plant (kg $plant^{-1}$)

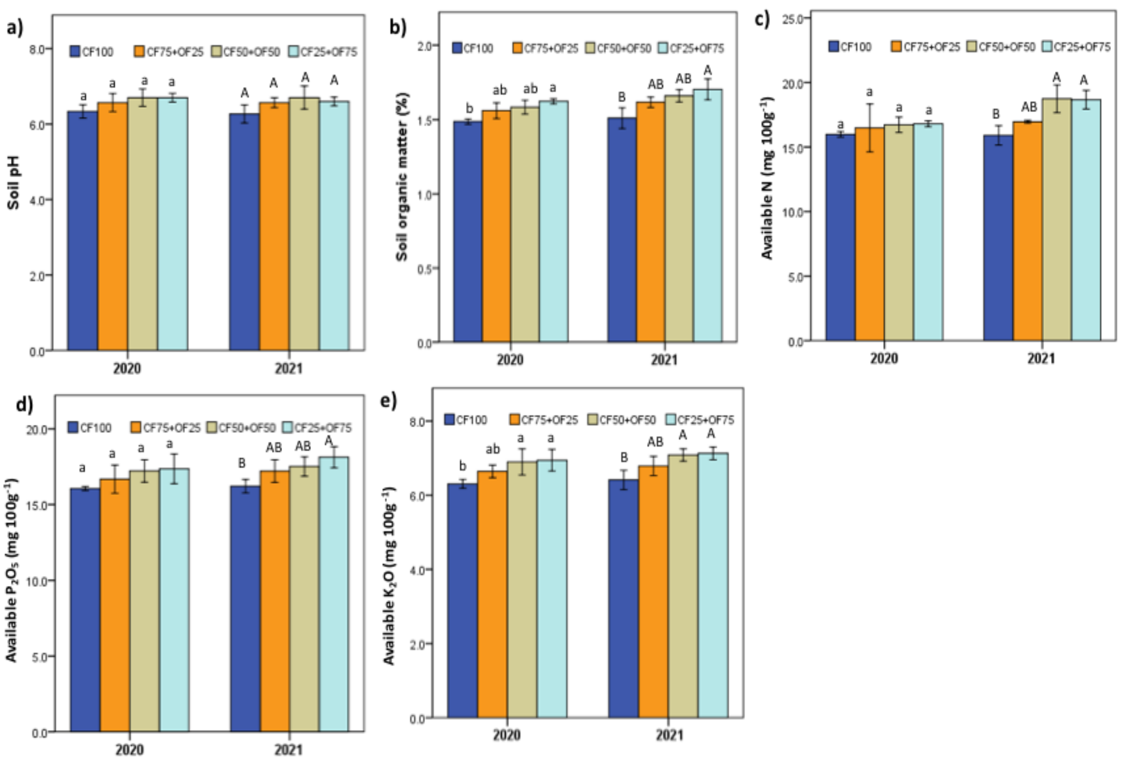

Figure 2. Effect of partial substitution of chemical fertilizer with microbial organic fertilizer on the soil chemical properties. Different letters within each bar group indicate significant differences between treatments at $P < 0.05$. Error bars represent the standard deviation calculated from three replicates. CF_{100}: 100% CF, CF_{75} + OF_{25}: 75% CF + 25% microbial OF replacing CF, CF_{50} + OF_{50}: 50% CF + 50% microbial OF replacing CF, CF_{25} + OF_{75}: 25% CF + 75% microbial OF replacing CF.

The substitution of chemical fertilizer with microbial organic fertilizer improved the fruit yield and yield components of tomato

Fertilizer treatment had a significant effect on tomato yield components, including fruit number and fruit weight (Figure 4). Compared to 100% CF, the substitution of CF with microbial OF generally increased the number of fruits per truss (NoFpT) and the number of fruits per plant (NoFpP) although the increases were significant only at 25 and 50% partial substitution of CF by microbial OF in both years. On the other hand, the fruit weight in CF_{75} + OF_{25}, CF_{50} + OF_{50} and CF_{25} + OF_{75} was also significantly higher than that in CF_{100} in 2020, while only CF_{75} + OF_{25} had a significantly higher fruit weight than CF_{100} in 2021. Islam et al. (2017) and Saha et al. (2019) showed that partial substitution of CF with OF significantly increased some yield components of tomato, which contributed to the increase in fruit yield.

Table 4. Multiple regression equation between fruit yield per plant and agronomic parameters as affected by partial substitution of chemical fertilizer with microbial organic fertilizer.

Multiple regression equation	R^2	Adjusted R^2	P value
$Y= -2.52 + 0.001ß_1 + 0.067ß_2 + 0.036ß_3$	0.951	0.946	***

*** mean not significant, significant at <0.001; Y: Fruit weight per plant (kg plant^{-1}); $ß_1$: shoot dry weight (g plant^{-1}); $ß_2$: number of fruits per plant (fruits plant^{-1}); $ß_3$: average fruit weight (g fruit^{-1}).

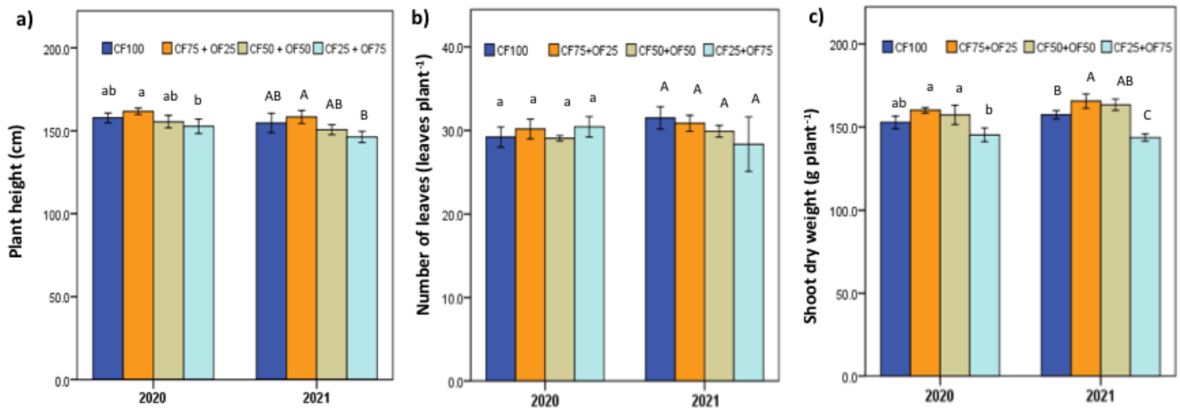

Figure 3. Effect of partial substitution of chemical fertilizer with microbial organic fertilizer on the plant height (a), leaf number (b) and shoot dry weight (c).
Different letters within each bar group indicate significant differences between treatments at P<0.05. Error bars represent the standard deviation calculated from three replicates. CF_{100}: 100% CF, CF_{75} + OF_{25}: 75% CF + 25% microbial OF replacing CF, CF_{50} + OF_{50}: 50% CF + 50% microbial OF replacing CF, CF_{25} + OF_{75}: 25% CF + 75% microbial OF replacing CF.

The partial substitution of CF with microbial OF generally increased fruit yield of tomato especially in CF_{75} + OF_{25} compared to 100% CF in both years. The fruit yield was not significantly different among treatments with partial substitution with microbial OF in 2020 and between CF_{75} + OF_{25} and CF_{50} + OF_{50} in 2021. These indicate that 25% substitution of CF with microbial OF was optimal to produce high fruit yield. Previous studies also reported that 25% substitution of CF with OF was optimal in tomato (Wu et al., 2022) and in the wheat-maize system (Guo et al., 2016). On the other hand, other reports also showed that the highest fruit yield of tomato was obtained at 1/3 CF combined with 2/3 vermicompost (Saha et al., 2019), or 40% CF combined with 60% organic manure (20% of each cow dung, poultry manure, mustard oil cake, and vermicompost) (Islam et al., 2017). The higher fruit yield under partial substitution of CF with OF is the result of an improved of soil physical and chemical properties and biological activity (Guo et al., 2016; Ye et al., 2020; Wu et al., 2022; Zhai et al., 2022) and more vigorous root system (Zhai et al., 2022) which makes the plant take up water and nutrients more efficiently from the soil. With the exception of the quantity of fruit trusses, most of the traits in this study had significant positive association with each other (Table 3). The NoFpP, NoFpT, average fruit weight (AFW), and SDW showed strong positive correlations with fruit weight per plant (FWpP). This suggests that when one of these traits' values increases, the attribute with which it is most closely related also increases. Sushma et al. (2020), Sanam et al. (2022) and Tao et al. (2022) showed significant and positive correlation between fruit yield and the NoFpP and AFW in tomato. The correlation measures the degree of a relationship between two independent traits that influence the yield positively or negatively, but correlation analyses alone may sometimes insufficient (Sanam et al. (2022). To quantify the extent of contribution of each trait individually and collectively to yield, some methods are commonly used such as the regression model (Kasu-Bandi et al., 2019; Sanam et al. (2022) and path coefficient (Monamodi et al., 2013; Sushma et al., 2020). In this study, regression analysis showed that NoFpP had the greatest impact on tomato fruit yield when CF was partially substituted with microbial OF (Figure 5). Based on the prediction power, NoFpP accounted for 89% of the variance in FWpP leaving only a small variance (11%) in FWpP that cannot be explained by this trait. Another trait which can significantly account for the FWpP is the AFW which can explain the 49% variance in FWpP. The growth traits, namely plant height and number of leaves per plant also contributed although a bit minimal to fruit yield of tomato at 30 and 11%, respectively. Several studies also showed NoFpP as the most important trait for tomato yield (Monamodi et al., 2013; Sushma et al., 2020; Sanam et al., 2022). Multiple regression analysis between FWpP and NoFpP, AFW and SDW showed significant positive relationships with multiple R^2 at 0.95 (Table 4). In other words, the changes in these three agronomic traits as affected by fertilizer treatment had 95% chances of affecting tomato yield.

The substitution of chemical fertilizer with microbial organic fertilizer improved fruit quality in tomato

Tomato has high nutritional value, which is dependent on the variety (Mazon et al., 2022) and management, such as irrigation (Li et al., 2023) and fertilizer (Saha et al., 2019; Ye et al., 2020; Buajaila et al. 2022; Li et al., 2023). In the current study, the ANOVA showed that fertilizer had significant effects on vitamin C, protein, total sugar, and nitrate content but was significantly with year nor the interaction between fertilizer and year (Table 2). Compared to 100% CF, the partial substitution of CF with microbial OF generally increased the content of vitamin C and protein (Figure 6). Vitamin C was significantly higher in CF_{50} + OF_{50} in 2020 and at CF_{25} + OF_{75} in 2021 than CF_{100}. Protein was significantly higher in CF_{50} + OF_{50} treatment than CF_{100} in both years. The total sugar was generally higher with microbial OF substitution to CF, compared to 100% CF but the difference was not significantly different among fertilizer treatments. Furthermore, nitrate content was reduced with microbial OF substitution to CF, compared to 100% CF. Overall, the results indicated that partial substitution of CF with microbial OF improves the fruit quality of tomato. Several studies have shown that combined application of OF and CF increased the contents of vitamin C, sugar, and protein (Ye et al., 2020; Tao et al., 2022; Li et al.,2023) while it decreased nitrate content (Ye et al., 2020). In this study, microbial OF substitution to CF at 75% produced lower nitrate content than with 100% CF. The nitrate content in plants is generally a result from an imbalance between the net uptake and assimilation rates (Cárdenas-Navarro et al., 1999) and can be influenced by excessive N applications (Umar & Iqbal, 2006). The microbial OF can enhance soil properties (Table 2) which can balance nutrients that can better regulate N uptake by the plants and possibly enhanced soil microbial activity that can help in the gradual mineralization of the nutrients, thereby

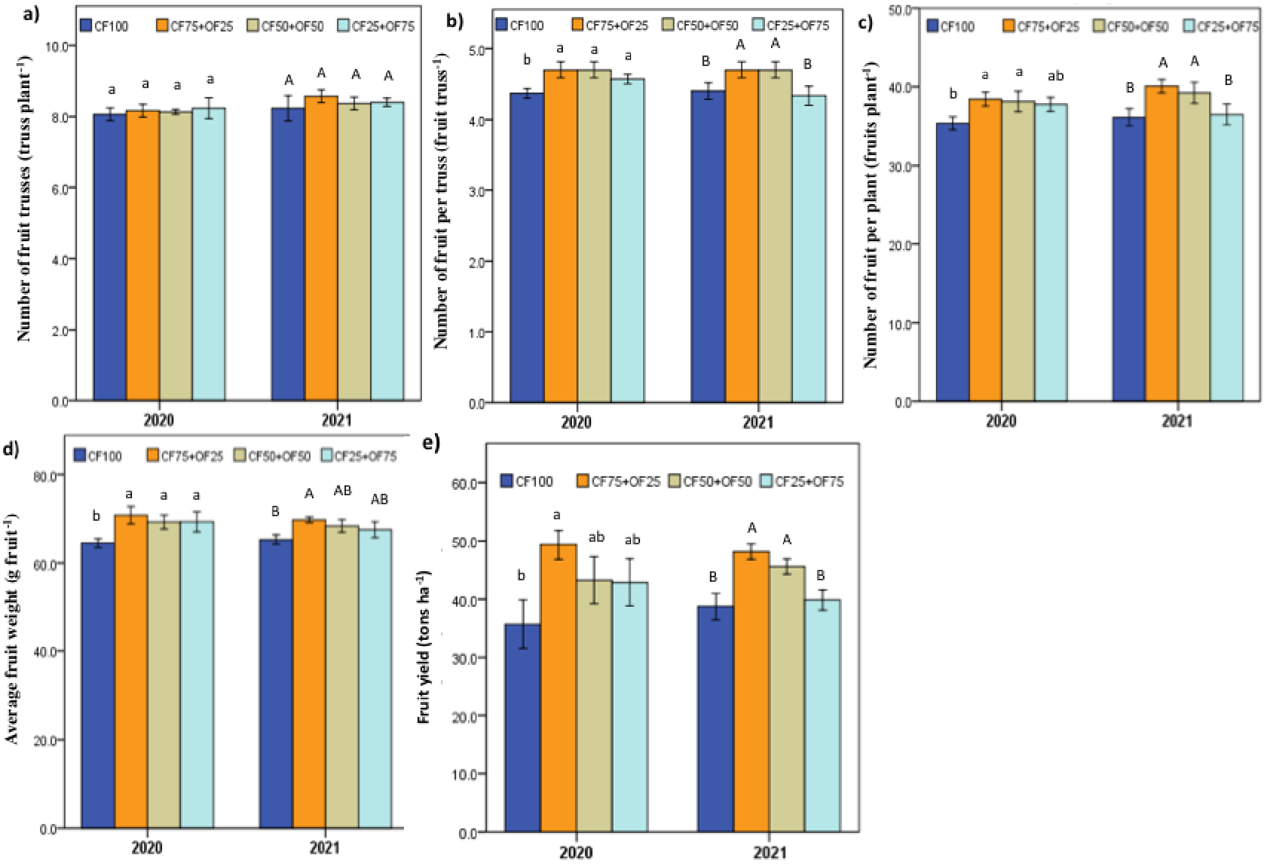

Figure 4. Effect of partial substitution of chemical fertilizer with microbial organic fertilizer on the tomato yield components and fruit yield. Different letters within each bar group indicate significant differences between treatments at P<0.05. Error bars represent the standard deviation calculated from three replicates. CF_{100}: 100% CF, CF_{75} + OF_{25}: 75% CF + 25% microbial OF replacing CF, CF_{50} + OF_{50}: 50% CF + 50% microbial OF replacing CF, CF_{25} + OF_{75}: 25% CF + 75% microbial OF replacing CF.

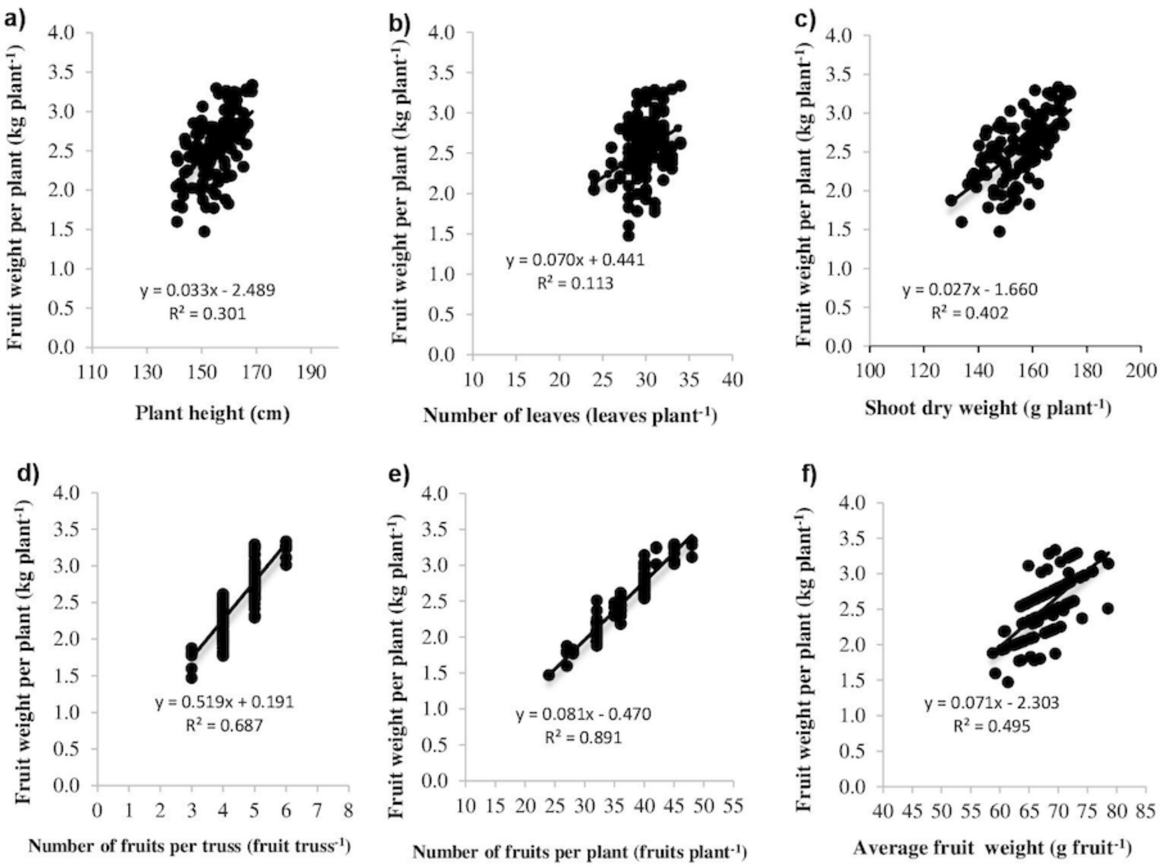

Figure 5. Scatterplot regression model between dependent (fruit weight per plant) and independent (plant height, number of leaves, shoot dry weight, number of fruits per truss, number of fruits per plant, average fruit weight) variables.

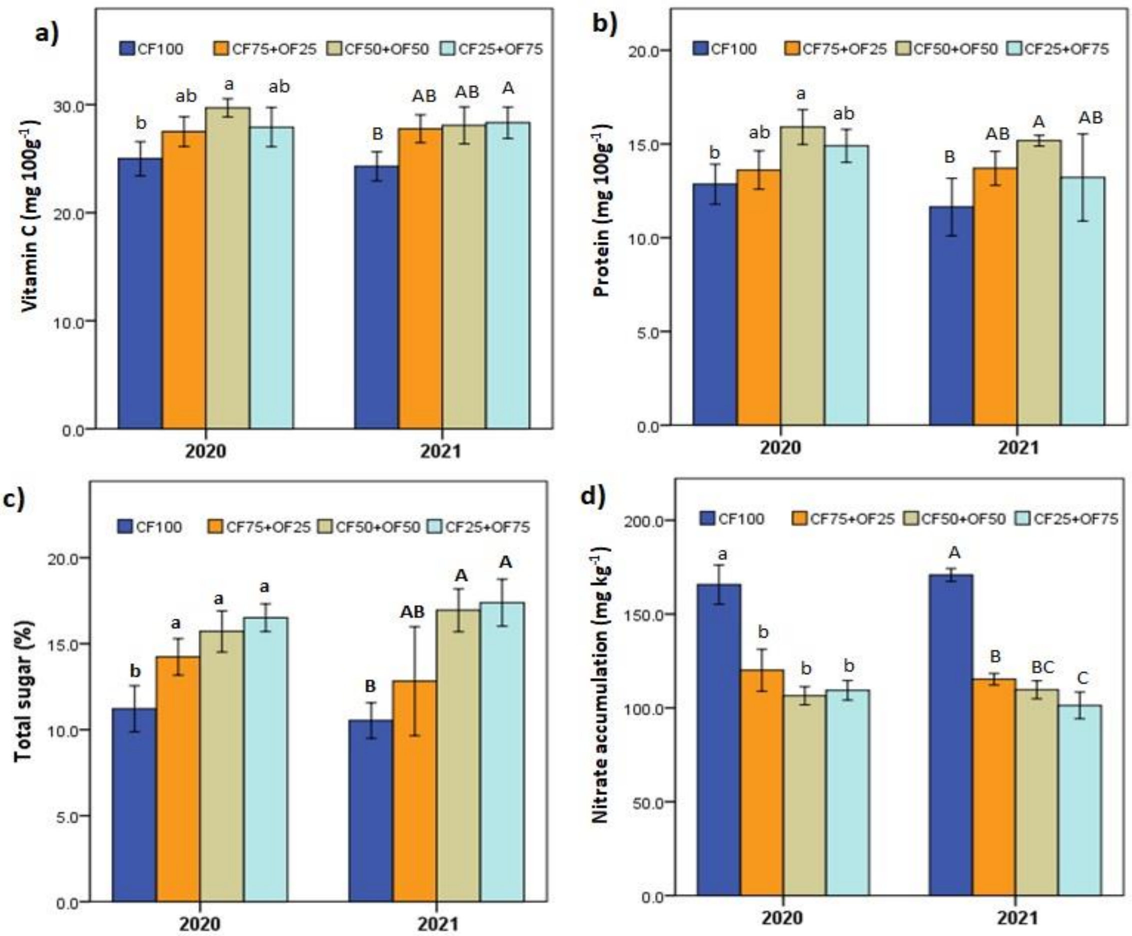

Figure 6. Effect of partial substitution of chemical fertilizer with microbial organic fertilizer on the tomato fruit quality traits. Different letters within each bar group indicate significant differences between treatments at P<0.05. Error bars represent the standard deviation calculated from three replicates. CF_{100}: 100% CF, CF_{75} + OF_{25}: 75% CF + 25% microbial OF replacing CF, CF_{50} + OF_{50}: 50% CF + 50% microbial OF replacing CF, CF_{25} + OF_{75}: 25% CF + 75% microbial OF replacing CF.

limiting the nitrate build up in tissues (Gao et al., 2023). Thus, proper balance between CF and OF could significantly reduce the amount of nitrate content in vegetables (Zhou et al., 2000). The application of OF generally had better fruit quality than those applied with CF (Khan et al. 2017). Oliveira et al. (2013) showed that organic farming may have subjected the tomato plants under mild stress promoting the accumulation of higher concentration of soluble solids as sugars and other compounds that can increase fruit nutritional quality such as vitamin C and phenolic compounds. Moreover, the improved soil chemical properties that made a balanced availability of soil nutrients as a consequence of the application of OF (Ye et al., 2020; Hashimi and Habibi, 2021; Fan et al., 2023). This implied that the application of CF with microbial OF substitution improves soil health and nutrient availability, leading to a higher sugar concentration in tomato fruits via enhanced photosynthesis and soil microbial activity.

Materials and methods

Plant materials

The tomato cultivar 'Savior' from Thailand was used in this study. This variety is being distributed by Syngenta Vietnam Limited Company and is widely grown in Northern Vietnam in recent years.

Experimental site description

The studies were conducted in the vegetable production farm of Viet-Japan Vegetables and Fruits Joint Stock Company, Hung Yen province, Vietnam (20°40'42.7" N 106°04'54.0" E) from February to June in both 2020 and 2021. The climatic data during the conduct of both experiments are shown in Figure 1. In both years the monthly average temperatures from February to April were generally the optimum for favorable growth of tomato except between May to June when the mean temperature started to increase (29.7°C to 32.1°C) which was slightly higher than optimum temperature favorable for tomato growth and development (Attoh et al., 2014). The total precipitation during the experimental period was slightly lower in 2020 than in 2021. Generally, sunshine durations similarly increased from February to June in both years. The soil in the experimental field is fluvisol, loam. The initial soil chemical properties before the conduct of the experiment were as follows: pH 6.53, organic matter 1.53 %, available N 16.13 mg 100 g^{-1}, available P 16.33 mg 100 g^{-1}, and available K 6.37 mg 100 g^{-1} (Supplementary Table 1).

Experimental design and management

The field experiments were laid our in a randomized complete block design (RCBD) with three replications. There were four treatments, namely: Conventional CF by local farmers -100% CF (CF_{100} as control); 75% CF + 25% microbial OF replacing CF (CF_{75} + OF_{25}); 50% CF + 50% microbial OF replacing CF (CF_{50} + OF_{50}); and 25% CF + 75% microbial OF replacing CF (CF_{25} + OF_{75}). The whole amount of N, P, K fertilizers applied were the same for all treatments (Table 1). The microbial organic fertilizer used in this study is marketed under the brand "Que Lam 01". This microbial OF was produced by Que Lam group joint stock company in Vietnam. The raw materials of product are peat, manure, and other organic materials, which fermented with beneficial microorganisms and supplemented with macronutrients and micronutrients. The microbial OF contains the following: 3% of N, 1% of P_2O_5 and 1% of K_2O, 15% of OM, N-fixing microorganism (1×10^6 CFU/g), phosphate solubilizing microorganisms (1×10^6 CFU/g) and cellulose-degrading microorganisms (1×10^6 CFU/g). The microbial organic and P fertilizers were applied as basal prior to transplanting. The N and

K from CFs were applied in two equal splits, each at the five-leaf and flowering stage. Seeds were sown in nursery beds. Twenty-five-day-old seedlings were transplanted in the field with two rows per plot at 60 cm × 50 cm spacing. Irrigation, weeding, and disease and insect management were done as necessary.

Data collection

Five tomato plants were randomly collected from each plot to evaluate growth indicators such as plant height, leave number per plant, and shoot dry weight at the harvest stage. Tomato fruits were harvested starting at 60 days after transplanting. Ripe fruits were manually collected twice weekly for up to 140 days after transplanting to record fruit number, fruit weight and fruit yield.

At the fully ripe stage, tomato fruits were used to determine the content of vitamin C, protein, total sugar and nitrate. The vitamin C content was measured with the 2,6-dichloroindophenol titrimetric method. Protein content was determined following the Kjeldahl method using DRB 200 - VELP sientifica, USD. The anthrone method was used to measure total sugar content (UV-2700, Shimadzu, Japan). Nitrate accumulation was determined following the spectrum method (UV-2700, Shimadzu, Japan).

After tomato harvesting in each year, soil samples were taken at a depth of 0-25 cm surface for chemical analysis. The pH soil was determined by using a glass electrode pH meter (Model: Mettler Toledo AG8603, China), organic matter by Walkley and Black method. The available N was determined by the Kjeldahl method (DRB 200 - VELP scientific, USA), available P by the Olsen method (UV-2700, Shimadzu, Japan), and available K by a flame photometer (UV-2700, Shimadzu, Japan).

Statistical analysis

The statistical analyses were done using the Performance Analytics package in R (Peterson et al., 2020). The data were subjected to ANOVA to detect effects of treatments and their interactions. Treatment means comparisons were subjected to Tukey HSD at 5% probability level. The Pearson correlations and regression analyses were performed using the Performance Analytics package in R.

Conclusions

This study showed that the partial substitution of CF with microbial OF could promote plant growth, and increase tomato fruit yield and quality by improving chemical properties of soil. Under Hung Yen province, Vietnam, the 25% substitution of CF with microbial OF is optimal for tomato production. The tomato fruit yield was greatly influenced by the number of fruits per plant, average fruit weight and the shoot dry weight. The changes in these three agronomic traits collectively influenced around 95% changes in the tomato yield. The present findings suggested that farmer should focus on increasing the number of fruits per plant to optimize fruit yield in tomato production.

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