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Nutrient uptake and yield of tomato (*Solanum lycopersicum*) in response to vermicast and vermi-foliar application

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Abstract The study aims to evaluate the nutrient uptake and yield of tomato applied with vermicast using band and fertigation methods and enriched with vermi-foliar. A split-plot design was used with three replications. The main plot employed vermicast application (band and fertigation), and the subplots were enriched with variable amount of vermicast and vermi-foliar: vermicast (VC) alone, VC + vermi-tea, and VC + vermi-leachate. Result showed that the level of soil pH, organic matter, P_2O_5, and K_2O was improved after two cropping periods. Both band and fertigation methods significantly increased ($P = 0.001$) the number of marketable fruits per plant and the fruit yield. Marketable yield was increased from 31.51 tons/ha in the vermicast alone to 36.51 tons/ha and NPK uptake of 5.15 g, 1.04 g, and 7.71 g, respectively, with the addition of vermi-tea. Tomato applied with vermicast using band method gave the highest yield of 35.60 tons/ha and nitrogen and phosphorus uptake of 4.41 g and 0.89 g. However, the nutrient uptake, as well as the number of marketable fruits per plant, was not influenced by band and fertigation methods and by the application of vermicast enriched with vermi-foliar, respectively.

Keywords nutrient uptake · fertilizer application methods · vermi-tea · vermi-leachate

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Introduction

Tomato production nowadays is dominating in Asia with China ranking first, following the decreasing volume produced by India, USA, Egypt, Iran, Italy, Brazil, Spain, and Uzbekistan (Bergougnoux 2014). In the Philippines, tomato production has an annual average production rate of 3.87% with Northern Mindanao, particularly Claveria and Bukidnon, as top producing regions next to the Ilocos region (Lesaca 2013).

In Claveria, tomato was once a major commodity before the tomato yellow leaf curl virus (TYLCV) infestation. This disease of tomato that causes severe damage was documented decades ago, and it spread in most parts of the country over time (Tsai et al. 2011). With this, the climate-favored tomato plantation in Claveria was wiped out by this TYLCV infestation leaving only the large-scale tomato producers to prosper. Small-scale farmers changed to other crops like corn, pineapple, and tobacco. Hence, the production was decreased not only because of TYLCV but also due to the escalating cost of inputs like fertilizers and pesticides.

Fertilizer application is often intensive in production as tomato is a heavy feeder crop. Aside from variety, fertilization is one important factor for maximizing the yield of tomato. Appropriate management is needed to attain high economic return to investment as well as reducing environmental hazard associated with improper fertilizer application (Mercado et al. 2010).

One way of ameliorating tomato production is the use of organic fertilizers such as vermicast from vermicomposting. Vermicast was reported to be effective in enhancing root formation, elongation of the stem, and production of biomass. Vermicompost has a higher level of available nutrients like nitrate or ammonium nitrogen, exchangeable phosphorous and soluble potassium, calcium, and magnesium derived from the wastes (Chanda et al. 2011). Additionally, other vermicompost by-products like the vermi-leachate and vermi-tea may enhance plant growth. Vermicompost tea improved mineral nutrient contents and microbial properties of the growth media. Humic acids from vermicompost produced superior growth compared with commercial humic acids when applied at the same rate (Edwards et al. 2006). Vermi-leachate is rich in amino acids, vitamins, nutrients like nitrogen, potassium, magnesium, zinc, calcium, iron, copper, and some growth hormones like auxins and cytokinin (Sinha et al. 2010). Findings of another study (Arthur 2012) suggested that vermi-leachate could be a solution for soil's phosphorous and potassium deficiency.

Vermicast, like any other organic fertilizers, can be applied to the plants using band and fertigation methods. Tomato growers commonly practiced fertigation, especially with organic fertilizers like chicken dung. In fertigation, farmers incorporated fertilizer in water and applied it to plants by drip system or by the use of sprinkler. In sweet corn, the yield was increased when applied with 90 kg N/ha using drip fertigation over band method of fertilization (Alcantara 2015). In band fertilization, fertilizer is applied at the side of the seedling, some distances away from it or at level with the seed. In another study conducted, it was revealed that yields of soybeans were increased by as much as 746, 598, and 941 kg/ha with the band, seed placement, and broadcast treatments, respectively (Ham et al. 1973). In both methods, nutrients from fertilizers are utilized by the growth and development of plants. Nutrient uptake parallels vegetative plant growth in many ways. Most crops take up the majority of the nutrients during the periods of vegetative growth and translocate stored nutrients to developing fruit during reproductive growth. Nutrients are lost from the plant after the dent stage (Mengel n.d.).

With the importance of tomato and its marketability coupled with availability of vermicast and other vermicomposting by-products, it is markedly essential to revive its production in Claveria, Philippines. The unchanging favorable climate of Claveria for tomato production can better be improved if studies using locally produced organic fertilizers like vermicast would be investigated and innovated. Hence, this work evaluated the nutrient uptake, and yield of tomato applied with vermicast using band and fertigation methods and enriched with vermi-tea and leachate.

Materials and methods

Experimental design and treatments

The study was conducted in a greenhouse using split-plot design with three replications using the AVTO 1004 tomato seeds from the World Vegetable Center (AVRDC). The main plot employed vermicast application (band and fertigation methods) and subplot with variable vermicast and vermin-foliar: vermicast (VC) alone, VC + vermi-tea, and VC + vermi-leachate. The area inside the greenhouse was divided into three blocks as replications. Each block was divided into two main plots and in which the main were further subdivided into three subplots. The plot measuring 1.5 m x 3.5 m accommodated two rows at 0.75 cm apart.

Preparation and collection of vermicast, vermi-tea, and vermi-leachate

Vermicast was obtained from USTP-CHED project on vermicomposting. Cow manure (50%) and sunflower (50%) were used as substrates for vermicomposting. Nutrient analysis of the vermicast revealed the following: pH, 7.0; N, 1.84%; P_2O_5, 0.03%; K_2O, 0.86 ppm; Ca, 1.58%; and Mg, 0.55 ppm ("Mercado, A.R. 2011. Integrated Soil and Crop Nutrient Management in Vegetable Crops in the Southern Philippines: Farmers' Practices and Researches in Vermicomposting" 2011).

The constructed bed for vermicomposting was provided with drainage and collecting panel where the leachate was gathered and collected. The liquid was collected weekly, placed in labeled plastic bottles, and stored in a safe room. Vermi-tea was prepared by soaking the vermicast using rainwater for one night with a 1:3 ratio of rainwater or dechlorinated water. It was stored in a tightly covered pail and placed in a cool, dry place. The vermi-tea contains total N, 0.92%; total P_2O_5, 0.74%; and total K_2O, 0.85%. Foliar fertilizer was applied by the spray method. Dilution of leachate and tea was done with a 1:10 ratio of water. The same amount (155 mL) of diluted vermi-leachate and vermi-tea were applied per plant at a 1-week interval. First treatment application was done at 30 days after transplanting at weekly interval thereafter and was done early in the morning.

Cultural management and practices

Seedlings were raised in trays using a sterile sowing medium. Plants were transplanted when the five-leaf stage was observed or about 4–5 weeks after sowing. Vermicast at 10 tons/ha was applied as fertilizer using band and fertigation methods. Vermiproducts were also applied as foliar following the treatment combinations.

Data gathering and analysis

Soil sampling and laboratory analysis

Soil samples were collected from the experimental area two times, before the conduct of the study and after the last harvest. Ten spots were sampled using a zigzag direction at a depth of 20 cm and was brought to the Soil and Plant Tissue Analytical Laboratory at Central Mindanao University for analysis. Soil analysis included soil pH by pH meter in 1:2.5 soil-water, organic matter by Walkley and Black method, available phosphorus by Bray's Method No. 1, and available potassium by ammonium acetate filtration with the help of a flame photometer.

Yield and yield component

The yield was obtained by counting and weighing the number of fruits per plant. The tomato was harvested seven times prior to termination. The fruits were sorted into marketable and non-marketable type every harvest. Marketable and non-marketable fruits were classified based on damage. Marketable fruits were those free from any blemishes, while non-marketable fruits were those with either mechanical or physiological damages. The yield was computed and expressed in tons/ha.

Nutrient concentration and uptake in plants

Destructive sampling was done for plant tissue analysis. Three plant samples per treatment per replication were randomly selected during first and last harvest. The samples were chopped and air-dried for 1 week and sent to Soil Laboratory at Central Mindanao University, Bukidnon, Philippines, for nutrient analysis. The nutrients analyzed include N, P, and K. Nutrient uptake determination according to Saidia et al. (Saidia et al. 2018) and nutrient concentrations in percentage were changed into mg/kg by multiplying by 10,000 and later on changed into g/kg and kg/kg of dry plant materials to get kg nutrient/ha: Nutrient uptake (kg/ha) = TDM (kg/ha) × nutrient content in plant (kg/kg) (Saidia et al. 2018)

Cost and return

Cost and return of plants per hectare were estimated based on the prevailing market price of tomato in the area. The computed cost of production per hectare was deducted from the gross return to obtain the net return per hectare:

Net return = gross return - total cost of production

Data analysis

Analysis of variance in split-plot design was used to analyze the data at a 5% level of significance based on the statistical model for the split-plot design as follows as reported in Saidia et al (Saidia et al. 2018):

$$Yijk = \mu + \beta i + Aj + \delta ij + Bk + ABik + \varepsilon ijk,$$

where Yijk = response level, μ = general effect or general error mean, βi = block effect, Aj = main plot effect, δij = the main plot random error (error a), Bk = subplot effect, ABik = interaction effect between the main plot and the subject, and εijk = subplot random error effect (error b).

Comparison of means was done with Tukey's test at $p \leq 0.05$. Pearson correlation was also performed in yield and nutrient uptake.

Results and discussion

Soil characteristics

Before treatment application, soil pH was 5.07, a strongly acidic and not favorable for vegetable crops specifically for tomato. The pH preference of tomato is 5.5–7.0. Initial organic matter of 1.6% was very low, while extractable P and K were only 21.16 ppm and 102 ppm, respectively.

After the addition of vermicast and vermi-foliar, soil pH was raised by 7.2 regardless of the methods of fertilizer placement used. The increase of soil pH was either by mineralization of organic anions to CO_2 and water. Soil organic matter was likewise raised by up to 3.9% upon addition of vermicast and vermi-foliar.

Nitrogen in the form of NH_4^+ ion was a contributing element for cation exchange capacity or CEC and is easily adsorbed by the soil rich in humus. Azarmi et al. (Azarmi et al. 2008) reported that the addition of vermicompost at a rate of 15 tons/ha substantially increased contents of soil total organic carbon, total N, P, K, Ca, Zn, and Mn.

The extractable phosphorus content in the soil was also raised to 70.08 ppm. Phosphorus ion is also a contributing element for CEC. Arancon et al. (Arancon 2006) also recorded a significant increase in orthophosphates in vermicompost-treated soils as compared to the controls.

Addition of vermicast and vermi-foliar increased the potassium content of the soil to 196.50 ppm. Vermicast, which is rich in humus, would eventually increase the cation such as NH_4^+ and K^+ contents in soil due to increase adsorption. Romero (Romero 2014) in the study on rice production under organic area reported that application of organic fertilizer markedly improved the soil properties such as available P, exchangeable K, organic matter, and pH both for fully converted and under conversion areas after two cropping seasons.

Tomato yield

Tomato plants reached up to seven total numbers of harvesting periods. Statistical analysis revealed no significant difference in the fertilizer placement, vermicompost products, as well as their interactions. Vermicast enriched with vermi-tea had the most number of marketable fruits of 212. As reported by Sinha (Sinha et al. 2010), vermi-foliar applied in tomato produced healthy fruits with unique shine over it. Vermicast alone had the least total number of fruits per plant of only 182 (Table 1).

Total yield was obtained in seven harvesting periods. Tomato applied with vermicast in band method gave a significantly higher yield of 35.60 tons/ha compared to those plants applied with vermicast using the fertigation method of application with yield of 32.23 tons/ha. Similar findings were obtained by Alcantara et al. (2014) under the open field. Application of vermicast and vermi-foliar influenced significantly the marketable yield. Result of the study revealed that the addition of vermi-tea in vermicast gave the highest yield of 36.51 tons/ha· which is significantly higher compared to tomato applied with vermicast alone having a yield of

Table 1 Number of marketable fruits per plant in response to vermicast application using band and fertigation methods and enriched with vermi-foliar

Vermicast fertilizer placement (MP)	Vermicompost products (SP)			Mean ^{ns}
	VC alone	VC + vermi-tea	VC + vermi-leachate	
Fertigation method	178	211	164	184
Band method	185	213	201	200
Mean ^{ns}	182	212	187	

MP, main plot ^{ns}; SB, Sub plot ^{ns}; MP x SP ns, cv (a) = 9.46% cv (b) = 10.75%

31.50 tons/ha, but not statistically different in the vermi-leachate application with a marketable yield of 33.73 tons/ha. The significant increase in yield can be attributed to the increased number of fruits produced per plant as influenced by spraying tomatoes with vermi-tea and vermi-leachate. Romero (2014) explained in the study on rice that the increase in yield could also be attributed to the complementation of slow release of nutrients from solid organic fertilizer (vermicast in this study) and the readily available plant nutrients from the foliar sprays (vermi-tea in this study) such that, within the growth and development of the crop, there is continuous availability of plant nutrients that supported the development of more fruits. A significant difference in the interaction means was likewise observed in the marketable yield of tomato (Table 2).

NPK uptake

Every crop has a unique nutrient uptake pattern. Nutrient uptake normally takes two forms. Nutrients are either taken up by the roots, which is dominant in

Table 2 Yield of tomato in response to the application of vermicast applied using band and fertigation methods and enriched with vermi-foliar

Vermicast fertilizer placement (MP)	Vermicompost product (SP)			Mean **
	VC alone	VC + vermi-tea	VC + vermi-leachate	
Fertigation method	29.52^b	37.88^a	29.29^b	32.23^b
Band method	33.49^a	35.14^a	38.17^a	35.60^a
Mean *	31.51^b	36.51^a	33.73^{ab}	

MP, main plot **; SB, subplot *; MP x SP **, cv (a) = 0.70% cv (b) = 7.47%

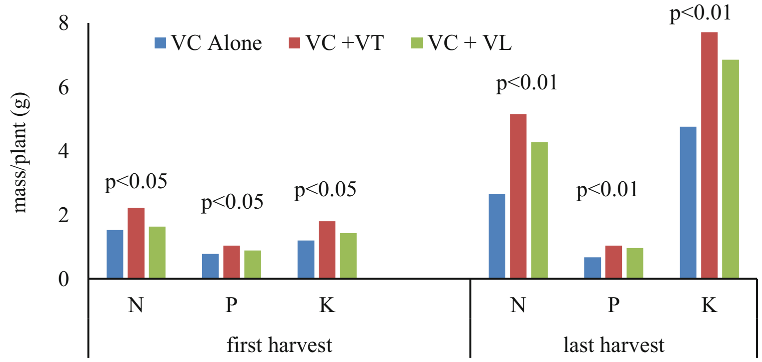

Fig. 1 NPK uptake of tomato applied with vermicast enriched with vermi-foliar

nutrition or by the leaves, which is only additional in nutrition (Sárdi 2011). These two forms of nutrient uptake were applied in the study. Nutrients from vermicast applied through fertigation and band are taken up by the plants through roots, while nutrients from vermin-tea and vermi-leachate, which are additional nutrition applied through foliar, are taken up mostly by the leaves. In addition to nutrient being added to the soil as fertilizers, most plants can absorb mineral nutrients applied to their leaves as sprays in a process known as a foliar application (Taiz and Zeiger 2002).

Tomato applied with vermicast using band method gave higher uptake of NPK compared to fertigation method with values 1.75, 1.09, and 1.59 g/plant NPK, respectively, for the first harvest and 4.41, 0.89, and 6.38 g/plant NPK in the last harvest. However, statistical analysis revealed no significant variations in the treatment means. This finding was supported by the study, which recorded no significant difference in the method of K fertilizer placement used in paddy rice (Ali et al. 2005). Total nitrogen uptake, phosphorus, and potassium by tomato were significantly enhanced by the application of vermin foliar (Fig. 1). Vermicast enriched with vermi-tea significantly had higher NPK uptake compared to vermicast alone and vermicast enriched with vermin-leachate. Addition of vermi-tea and vermi-leachate increased the nitrogen available in the soil. This was probably because of the addition of extra ammonium nitrates from the vermicompost due to mineralization. Nitrogen exists as ammonium nitrate ions, $NH4+$, and $NO3-$ in the soil for ready uptake (Manyuchi and Mudamburi 2013).

Correlation of fruit yield to NPK uptake

Pearson correlation coefficients were generated for the tomato fruit yield in response to NPK uptake of tomato. Positive relationships between yield to N ($r = 0.83^{**}$); P ($r = 0.68^{**}$); and K uptake ($r = 0.66^{**}$) exist. The responses of these parameters to fruit yield were positive

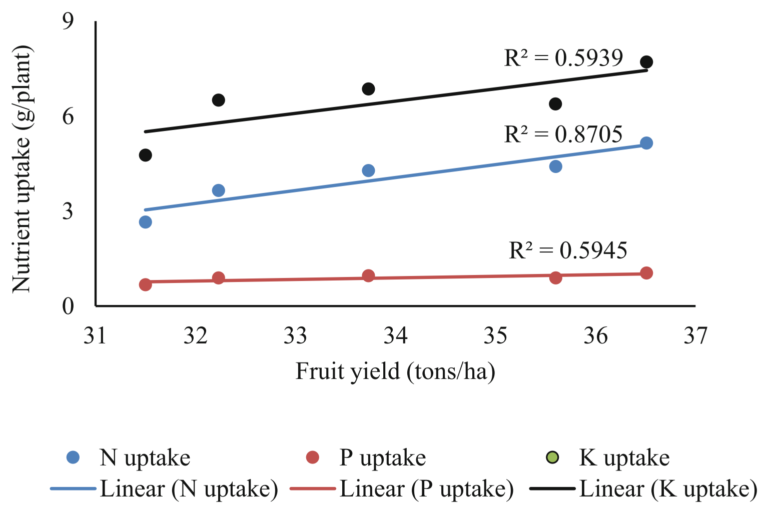

Fig. 2 Relationship of NPK uptake to fruit yield

and linear (Fig. 2). The positive relationship of these parameters explains the importance of nitrogen, phosphorus, and potassium to the growth and yield of tomato, more specifically. Nitrogen is absorbed by plants in the form of NH_4^+ and NO_3^-. An adequate supply of nitrogen is associated with vigorous vegetative growth and deep green color. Plants absorbed most of their phosphorus as the primary orthophosphate, ion, $H_2PO_4^{2-}$. Phosphorus is a constituent of nucleic acid, phytin, and phospholipids. Potassium, on the other hand, is absorbed as the potassium ion, K^+, and is found in soils in varying amounts. Plant requirements for this element are quite high (Havlin et al. 2005). This is relatively true in the analysis of tomato uptake for potassium in this particular study. Potassium plays a key role in charge balance and certain metabolic and transport processes, as well as turgor regulation; it influences fruit shape, reduces ripening disorders, and enhances acid concentration (Nzanza et al. 2014).

Parameter	Correlation coefficient, r	F-test
Fruit yield x N uptake	*0.8303*	**
Fruit yield x P uptake	*0.6775*	**
Fruit yield x K uptake	*0.6648*	**

Cost and return analysis

The prevailing price of tomato during the conduct of the study was Php 500.00/crate or Php 16.00/kg. The result showed that the band method of vermicast application had higher gross income, net income, and return of investment compared to the fertigation method (Table 3). However, the application of vermicast enriched with vermi-tea gave the highest gross income, net income, and ROE in spite of the additional cost for vermi-tea. Application of vermi-leachate also gave a higher gross income, net income, and ROE compared to vermicast alone (Table 3).

Table 3 Cost and return analysis of one-hectare tomato production

Treatment	Gross income (Php)	Total expenses (Php)	Net income (Php)	ROE (%)
Fertilizer placement				
Fertigation	515,680	119,550	396,130	76.81
Band	569,600	116,150	453,450	79.61
Vermiproducts				
VC alone	504,000	116,150	387,850	76.95
VC + VT	584,160	125,550	458,610	78.51
VC + VL	539,680	116,150	423,530	78.48

Conclusion

The number of marketable fruits per plant and fruit yield was influenced by fertilizer placement methods. Application of vermicast enriched with vermi-tea and vermi-leachate significantly influenced the marketable yield of tomato. Vermicast enriched with vermi-tea significantly had higher NPK uptake compared to vermicast alone and vermicast enriched with vermi-leachate. Vermicast application enriched with vermi-tea obtained the highest ROE.

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