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Modeling the Dynamics of Soil Organic Matter Accumulation from Leaf Litterfall as Affected by Tillage Practices in Mango Orchard

Fernan T. Fiegalan[1,2,*], Cherry L. Ringor[1], and Tolentino B. Moya[1]

[1]Institute of Environmental Science and Meteorology, University of the Philippines Diliman, Quezon City 1101 Philippines
[2]Department of Soil Science, College of Agriculture, Central Luzon State University, Science City of Munoz, Nueva Ecija 3120 Philippines

[*]Author for correspondence: E-mail: ftfiegalan@clsu.edu.ph

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This study was undertaken to determine long-term soil organic matter (SOM) accumulation dynamics from added mango leaf litter (MLL) into tilled (MT) and non-tilled soil (MnT) through integrated field experiment (bio-physico-chemical edaphic properties) and system dynamics modeling. Field data shows that the coarse (Lf) and fine (Fn) fractions of SOM have no significant difference ($p > 0.05$) between MT and MnT during the dry season. In contrast, there is a significant difference ($p < 0.01$) in the Fn fraction between MT and MnT during the wet season. The total N, available P, exchangeable K, as well as the collembola, bacteria, and fungi in the soil were also assessed. Of these parameters, the available P and exchangeable K have a significant difference between the MnT and MT during the dry season. In comparison, the total N and collembola significantly differed during the wet season. The results of the field experiment were used in the parametrization to build the SOM accumulation model. The 20-year simulation showed that the incorporation of MLL into the soil through tillage increased SOM from 3.09% to 3.13%, with an average of 2.78 ± 0.018%. In the non-tilled orchard, SOM also increased from 3.09% to 4.23%, with an average of 3.59 ± 0.035%. This SOM level can sustain the fertility and productivity of the mango agroecosystem. The increase in SOM is accounted for by the coarse fraction both in tilled and non-tilled plots. Given the foregoing, with minimum tillage, mango orchards can be developed into crop-based systems.

Keywords: leaf litter, mango orchard, mechanistic modeling cum field experimentation, soil organic matter, tillage

Abbreviations: Fn—fine fraction, Lf—coarse fraction, MLL—mango leaf litter, MnT—non-tilled plot, MT—tilled plot, SOM—soil organic matter

INTRODUCTION

Leaf litter is a major source of organic matter and energy to soil. As leaf litter undergo decomposition, substantial amounts of nutrients and organic matter are returned to the soil. Hence, the utilization of leaf litter in mango orchard to sustain or enhance the soil organic matter (SOM) status is a promising management strategy. Litterfall production is correlated to ambient temperature and seasonal rainfall (Talemos et al. 2018). Rainfall may induce shedding of both senescent (Lu and Liu 2012) and non-senescent leaves (Scheer 2009). In the Australian wet tropical region, litter fell mostly in the wet and warm months in the region, but other peaks occurred throughout the year (Parsons et al. 2014). However, Zhang et al. (2014) reported that litterfall production in the wet season is less compared to the dry seasons in tropical forest ecosystem worldwide. Leaf litterfall in a cocoa ecosystem in lowland humid Ghana ranged from 4.6 to 8.4 ton ha^{-1} yr^{-1} dry weight depending on the maturity of the cocoa trees (Dawoe et al. 2009). For mango orchard, a study in Zimbabwe showed that a mature mango tree produces about 22 kg of leaf litter annually (Musvoto et al. 2000). This translates to 4.4 ton ha^{-1} yr^{-1} for a recommended 200 mango trees per hectare.

Based on physical fractionation, SOM can be broken down into coarse fraction (Lf) ranging from 0.05–2.00 mm and fine fraction (Fn), which is < 0.05 mm (Wander 2004; von Lutzow et al. 2007). Functions of SOM fractions in fertility assessment are specific and exclusive. According to Barrios et al. (1996) as cited by Beedy et al. (2010), nutrient releases from the decomposing organic material is attributed to mineralization of the SOM coarse fraction.

Improved chemical properties of the soil such as nutrient holding and buffering capacities are all associated with SOM fine fraction.

One source of Lf and Fn fractions is in-situ mango leaf litter (MLL). The physical and chemical decomposition of leaf litter from mango trees can sustain the accumulation of Lf and Fn fractions in the SOM pool. The community of edaphic decomposers, i.e. collembola, bacteria, and fungi, are involved in the physical fragmentation and chemical alteration of organic materials added into the soil (Chapin et al. 2012). According to Chahartaghi et al. (2005) and Marriott and Wander (2006), the biophysical decomposition of organic materials by collembola produced coarse fraction of SOM. Bacterial and fungal colonization in SOM fractions promote mineralization and humus production (Wander 2004). Plaza et al. (2013) found out that it was highly favorable for SOM to accumulate particularly in less disturbed soil condition, wherein it was mostly the case in mango orchard. Overall, the decomposition of MLL enhanced SOM and improved the fertility condition in mango orchards (Musvoto et al. 2000).

The intercropping of cash crops involves tillage, which was reported to have unfavorable effect on SOM status (Brevik 2013; Bot and Benitez 2005). However, farmers practice incorporation of leaf litter into the soil through tillage as a management strategy for SOM accumulation and agricultural wastes management. In general, the study was undertaken to determine the changes in SOM accumulated from MLL in tilled and non -tilled mango orchards. Specifically, it was conducted with the following objectives: (i) to examine the accumulation dynamics of coarse and fine fractions of SOM between tilled and non-tilled mango orchard, (ii) to compare the effects of mango leaf litter incorporation through tillage and no tillage of mango leaf litter on changes in the soil bio-physico-chemical properties, and (iii) to investigate through modeling the long-term impacts of the temperature and soil moisture on the state of SOM in tilled and non-tilled mango orchard.

MATERIALS AND METHODS

In Situ Assessment of SOM

Site Description

The in situ experiment was conducted at the mango orchard of the College of Agriculture, Central Luzon State University. The orchard was located in the middle of the paddy rice field of the university, situated at 15° 44′ 9.82″ N; 120° 56′ 24.10″ E. It was established in a 90 m x 60 m land area with a planting distance of 7 m x 10 m with about 75 mango trees. The orchard was in mature stage condition, actively bearing fruits for more than a decade and still productive during the study period. The understory was covered with partially decomposed leaf litter with an average leaf litter fall of 11,200 kg ha^{-1} yr^{-1}.

The study area has high rainfall occurrence, receiving a total rainfall of 1,867 mm from January–December 2017 and with an average annual temperature of 28.45°C (PAGASA-CLSU 2017).

Experimental Layout and Soil Sampling

About 900 m^2 area within the mango orchard was used for the in-situ experiment. The area was divided into two experimental plots with three replicates of 7 m x 20 m subplots. The first experimental plot was assigned to tilled soil treatment (MT) while the second was assigned to non-tilled soil treatment (MnT). The composite samples from each experimental plot were collected at random. Leaf litter in the understory of the orchard were utilized as source of SOM accumulation. In MT, leaf litter were incorporated into the soil through mechanical ploughing at a depth of about 10 to 15 cm, whereas the leaf litter in MnT were left undisturbed on the soil surface. Soil sampling was done before the addition of MLL in both wet and dry seasons and at a 14 day interval for a total of six samplings for three months. These were used for the calibration and validation of the 20 year simulation of SOM accumulation in tilled and non-tilled soil. Soil samples were collected using a core sampler at 10 cm depth and used for the analysis of soil nutrients (N, P and K), moisture content, and physical fractionation of SOM. For biological assessment, soil samples were scraped from the surface of a 0.5 m x 0.5 m quadrat.

Soil Analysis

Soil parameters were analyzed using standard methods. For the soil microorganism colony count, the serial dilution technique was used (Cornejo et al. 1994; Dada and Aruwa 2014). Nutrient agar (NA) was used to determine the bacterial colony count while potato dextrose agar (PDA) with 0.5 ml streptomycin in 100 ml media was employed for fungal colony count. Serial dilutions of 10^{-3} to 10^{-6} were used to count the colony. For bacteria in NA, colony count was done after 24 h of incubation under ambient temperature, while three to five days for fungi in PDA. For the determination of the population density of collembola, the Berlese-Tullgren funnel technique was used to extract the collembola from the soil and leaf litter (Bano and Roy 2016). Scrapped soil and leaf litter samples were placed on the Berlese funnel for 24 h heated with a 40 watt light bulb. As the surface of the sample becomes heated and desiccated, the collembola move down and are driven out from the sample. The collembola were then collected into a specimen tube filled with 70% ethyl alcohol which is placed below the funnel. For soil moisture quantification, gravimetric method was used (PCARR 1980). Soil samples were placed in a 105°C oven for 24 h. For soil nutrient analysis, samples from the core sampler were air-dried, pulverized, and sieved using a 2 mm mesh. The modified Kjeldahl method was used to determine the Total N, Bray2 method for the available P, and flame photometer method for the exchangeable K using Ammonium Acetate as an extracting solution (PCARR 1980).

SOM Fractionation

The Lf (0.05–2 mm) and Fn (< 0.05 mm) SOM fractions were determined using the physical method of fractionation (Wander 2004; von Lützow et al. 2007). Soil samples from the core samplers were air-dried and sieved in a 2 mm mesh to discard non-soil particles. Wet sieving technique was used to separate the coarse particulate matter from the fine particles using a 0.053 mm sieve. Dry combustion analysis (Angers et al. 1993; Puget et al. 1995; Needelman et al. 1999) was used to determine the total carbon content (%C) of Lf fraction using the TOC Analyzer (Primacs Series-Skalar), while the Walkley-Black method was used for the determination of %C in Fn fraction (Walkley and Black 1934).

SOM Modeling

Model's Structure and Components

Soil organic matter accumulation in mango orchard was modeled using the system dynamics approach. The SOM model was structured based on the two-compartment series (Manzoni et al. 2012). System Thinking Experimental Learning Laboratory with Animation (STELLA) platform (https://iseesystems.com/) was used to build and run the model. Figure 1 shows the organization of the edaphic components to simulate the process of SOM accumulation in mango orchard. SOM fractions Lf and Fn were modified through time as affected by mango leaf litter input and the edaphic properties: biological, soil nutrients, soil temperature, and moisture content. The addition of MLL into the soil through tillage and no-tilling treatments were also included in the model. In addition, the effects of tillage in the physical fragmentation of MLL and disturbance in the population density of soil biota were incorporated. Multiple correlation analyses (Excel software) regarding the aforementioned relationships of tillage disturbance with soil biota were used to determine the degree of involvement of collembola, fungi, and bacteria in model structure. Also, the soil nutrient content, N, P, K, in relation to soil biota were also correlated for the model structuring. The recurring condition of SOM fractions due to physical degradation as well as the C mineralization through chemical decomposition was also structured in the model. Although soil *pH* could affect the decomposer population, particularly that in extremely acidic and alkaline soils, it was not included in the model. Extreme soil *pH* condition was not observed in mango orchards in the study area; it ranged between 5.5 and 6.5. Thus, above or below this *pH* range the model will have limited application.

Parametrization

Based on the leaf litter fall rate of 11,200 kg ha^{-1} yr^{-1} in the mango orchard (Fiegalan et al. 2017), 5,600 kg ha^{-1} was used as initial crop residue input for decomposition into Lf and Fn fractions for each wet and dry season. The leaf litter rate was derived from a 6-month surface accumulation in the field. The accumulation of SOM fractions in each compartment was calculated using mathematical Equations 1 and 2. The percentage change of SOM in a given time was also computed using Equation 3.

$$Lf(t) = kLf\,(t - dt) + \{ifw\,(kLf) - \mathit{ifw}\,(Fn) - \mathit{ofw}\,(kLf)\} * dt \quad (1)$$

where: Lf(t) is the stock (accumulation) of Lf fraction at any given time of simulation; kLf is the current stock of Lf fraction before simulation; *ifw* inflow rates of materials into different stocks; *ofw* outflow rates of materials from Lf stock; t – dt is the simulation interval of the model.

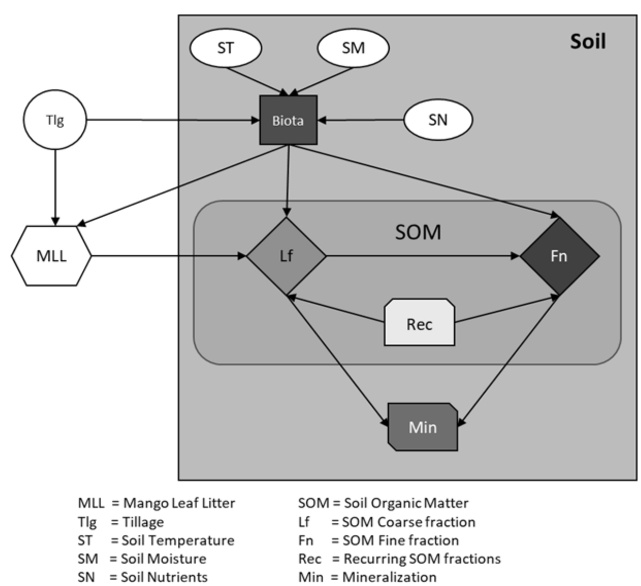

Fig. 1. Process flow of the SOM model in Lf and Fn fractions.

$$Fn(t) = kFn\,(t - dt) + \{ifw\,(kFn) - ofw\,(kFn)\} * dt \quad (2)$$

where: Fn(t) is the stock (accumulation) of Fn fraction at any given time of simulation; kFn is the current stock of Fn fraction before simulation; *ifw* inflow rate of materials into Fn stock; *ofw* outflow rate of materials from Fn stock; t – dt is the simulation interval of the model.

$$\%\Delta SOM / t = [(X_i - X_o) / X_o] * 100 \quad (3)$$

where: %ΔSOM/t is the percent change of SOM in every period (*t*) of assessment; X_o is the SOM from the previous assessment; X_i is the current SOM value.

SOM fractions were represented by stocks wherein either the accumulation or reduction was modified through flows. The accumulation of materials in the Lf and Fn fractions were modeled using the flows which represent different processes. In Lf inflows (*ifw*), both the MLL fragmentation and the recurring state of Lf pool were quantified. The MLL fragmentation into particle size that qualifies to be a SOM fraction (2 mm diameter) was either due to mechanical fragmentation through tillage or by biological fragmentor—the collembola. The outflows (*ofw*) in Lf represent the C-mineralization and the conversion of Lf fraction to Fn fraction. The previous outflow of Lf serves as the inflow of the Fn (*ifw*). The mineralization of the Fn fraction (*ofw*) serves as its outflow. Further, the edaphic factors such as soil moisture, temperature, soil nutrients (N, P, and K), and the soil biota were assigned as the converters in the model. These converters were the factors that affect the rate of transfer of materials from Lf and Fn.

Model Calibration and Validation

The observed SOM in MnT and MT during wet and dry seasons were used to compare the simulated SOM projections. The observed SOM in MnT was used for calibration while the observed SOM in MT was used for validation. Statistical analyses were used to evaluate the projected SOM. For the calibration, the root mean squared error (RMSE) was used to determine the degree of deviation of the modeled SOM from the observed SOM. For the validation test, regression analysis was used to determine the degree of correlation between the modeled SOM from the observed SOM. To test the performance of the model, ANOVA was used.

Figure 2 shows the performance of the model for the calibration (Fig. 2A) and validation (Fig. 2B) tests. The simulated SOM in MnT showed minimal deviation from the observed SOM with RMSE of 0.0904. Likewise, the validation test for the modeled SOM in MT appeared to be significantly correlated with the observed SOM in MT

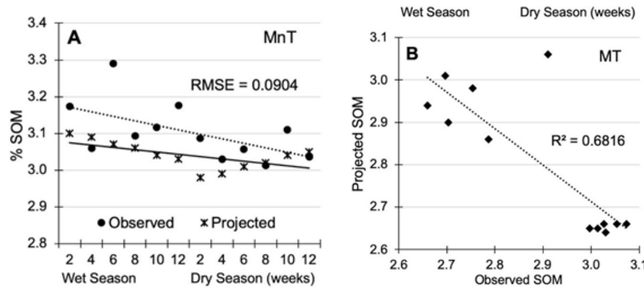

Fig. 2. Observed and projected SOM in non-tilled (MnT) and tilled (MT) plots for (A) calibration and (B) validation tests.

with R^2 of 0.6816 at $p < 0.01$. The model simulation was calibrated with minimal error and validated with significant correlation from the observed SOM.

Sensitivity of SOM Accumulation to Moisture and Temperature

The accumulation of SOM in MnT and MT was tested for differential sensitivity to varying soil moisture and temperature conditions. The SOM accumulation was tested at 9%, 18% and 27% moisture; wherein the average field capacity was 18%. The 50% reduction/addition of moisture from field capacity represents wilting/saturated condition. For soil temperature, the annual average of 28°C in field condition was also reduced by/increased to 5°C to test the sensitivity of SOM accumulation.

RESULTS AND DISCUSSION

Field Experimentation

SOM Fractions

Table 1 presents the ANOVA of SOM fractions in MnT and MT plots during wet and dry seasons. Lf fraction between MnT and MT were not significantly different ($p > 0.05$) in both wet and dry seasons. The Lf fraction of 0.81% (wet) and 0.77% (dry) in MnT was not statistically different from 0.78% (wet) and 0.82% (dry) in MT. These results showed that incorporation of MLL in the soil by tillage did not increase the Lf fraction of SOM.

In comparison, Fn fraction showed different results. During the wet season, Fn in MnT was 2.33% while in MT was 2.02%; the difference of 0.31% was significant ($p < 0.01$). In contrast, during the dry season, Fn fraction

Table 1. SOM fractions in mango orchard as affected by tillage practices.

%	Wet Season			Dry Season		
	MnT	MT	Difference	MnT	MT	Difference
Lf	0.81	0.78	0.03^{ns}	0.77	0.82	0.05^{ns}
Fn	2.33	2.02	0.31**	2.28	2.21	0.07^{ns}
SOM	3.14	2.8	0.34**	3.06	3.03	0.03^{ns}

**Significant at $p < 0.01$, ^{ns} Not significant at $p > 0.05$

between MnT (2.28%) and MT (2.21%) did not show significant difference ($p > 0.05$). The decrease in Fn fraction was attributed more to tillage than to incorporation of MLL into the soil.

The Lf and Fn fractions determine the SOM status in mango orchard. The 3.14% SOM in MnT was significantly higher ($p < 0.01$) than the 2.80% SOM in MT during the wet season. During the dry season, SOM status did not significantly differ between MnT and MT ($p > 0.05$). Soil tillage reduced SOM status by 0.34% in mango orchard during the wet season.

Effects of Leaf Litter Incorporation on the Edaphic Properties

Table 2 shows the biological and chemical properties of the soil in MnT and MT plots during the wet and dry seasons. Among the biological properties, collembola was greatly affected by the incorporation of MLL through tillage during the wet season. Collembola population in MnT with an average of 120 individuals per area was significantly higher ($p < 0.05$) compared to 101 individuals per area in MT during the wet season. There was no significant increase ($p > 0.05$) in collembola in MnT over MT during the dry season. As shown by Bandow et al. (2014), low soil moisture condition reduces the population growth of collembola. With regard to bacterial population, it did not significantly differ ($p > 0.05$) between MnT (141.61 cfu) and MT (140.94 cfu) during the wet season. For dry season, bacterial population in MnT was 89.78 cfu while 96.39 cfu in MT; there was also no significant difference ($p > 0.05$). Likewise, fungi population between MnT and MT showed no significant variation (> 0.05) during wet and dry seasons. MnT has 13 cfu and MT has 12.06 cfu during the wet season, while MnT has 12.50 cfu and MT has 12.83 cfu during the dry season. In sum, collembola population decreased with tillage during the wet season, while both bacterial and fungal populations were not affected by tillage in both wet and dry seasons. Tillage could increase soil aeration porosity and oxygen diffusion rate (Khan 1996) which may cause favorable conditions for fungal and bacterial growth, particularly during the dry season.

Table 2. Soil biological and chemical properties in mango orchard as affected by tillage practices.

	Wet Season			Dry Season		
	Biological Properties					
	MnT	MT	Difference	MnT	MT	Difference
Collembola (individual m^{-2})	119.61	100.78	18.83*	34.39	32.33	2.06^{ns}
Bacteria (cfu)	141.61	140.94	0.67^{ns}	89.78	96.39	6.61^{ns}
Fungi (cfu)	13	12.06	0.94^{ns}	12.5	12.83	0.33^{ns}
	Chemical Properties					
Total N (%)	0.065	0.052	0.013**	0.061	0.06	0.001^{ns}
Available P (ppm)	6.45	6.12	0.33^{ns}	8.22	5.56	2.66**
Exchangeable K ($cmol_c\ kg^{-1}$)	0.83	1	0.17^{ns}	0.9	0.84	0.06**

*Significant at $p < 0.05$, **Significant at $p < 0.01$, ^{ns}Not significant $p > 0.05$

Table 3. Multiple correlation analysis of SOM fractions and soil organisms.

	MnT		MT	
	Lf	Fn	Lf	Fn
Collembola	0.71**	0.24^{ns}	-0.55*	-0.97**
Bacteria	0.46^{ns}	0.37^{ns}	-0.48^{ns}	-0.75**
Fungi	0.16^{ns}	0.03^{ns}	0.24^{ns}	-0.15^{ns}

*Significant at $p < 0.05$, **Significant at $p < 0.01$
^{ns}Not significant at $p > 0.05$

Soil total N was 0.065% in MnT and 0.052% in MT during the wet season; the difference was significant ($p < 0.01$). During the dry season, soil total N in MnT (0.061%) and in MT (0.060%) were not significantly different ($p > 0.05$). For the available P, MnT has 6.45 ppm while MT has 6.12 ppm during wet season; the difference was insignificant ($p > 0.05$). Available P on MnT, 8.22 ppm, was 2.66 ppm higher than 5.56 ppm on MT ($p < 0.01$) during the dry season. Trends similar to those of the soil available P were observed for exchangeable K during the dry season. Soil tillage significantly reduced the soil total N in the wet season and available P and exchangeable K in the dry season.

Correlation Analysis

The correlation of SOM fractions with the soil biological communities is presented in Table 3. Collembola was positively associated (r = 0.71, $p < 0.01$) with Lf fraction in MnT while it is negatively correlated in MT (r = -0.55, $p = 0.03$). Similarly, this pattern of association of collembola was also shown in Fn fraction: MnT (r = 0.24, $p > 0.05$) and in MT (r = -0.97, $p < 0.01$). With respect to bacteria, the same pattern as collembola was observed. However, for the fungi association with the SOM fractions, both Lf and Fn in MnT and MT was insignificant. Overall, the result of the correlation analysis indicates the shift in function of collembola from physical fragmentors in MnT to grazers in MT. For bacteria, its mineralization function heightened from MnT to MT resulting in the mineralization of Fn fraction.

The degree of associations of soil nutrients, soil moisture, and temperature with the soil biota community are presented in Table 4. The collembola population was negatively correlated with available P (r = -0.63) while it is positively related with exchangeable K (r = 0.52) and soil moisture (r = 0.91). For the bacterial population, the only

Table 4. Multiple correlation analysis of the soil physico-chemical properties with the soil organisms.

	Collembola	Bacteria	Fungi
Total N	-0.32^{ns}	-0.23^{ns}	-0.16^{ns}
Available P	-0.63**	-0.31^{ns}	0.33^{ns}
Exchangeable K	0.52*	0.34^{ns}	0.02^{ns}
Soil Temperature	-0.43^{ns}	-0.25^{ns}	0.43^{ns}
Soil Moisture	0.91**	0.68**	-0.15^{ns}

*Significant at $p < 0.05$, **Significant at $p < 0.01$
^{ns}Not significant at $p > 0.05$

significant association with physico-chemical properties was found with soil moisture (r = 0.68). The fungal population had no significant correlation among the physico-chemical properties. These results indicate that collembola requires P and K nutrients, as well as sufficient soil moisture for fragmentation. However, the low association of bacteria and fungi with soil nutrients, r < 0.50; $p > 0.05$, indicates that their utilization of nutrients comes from the mineralization of the decomposing MLL.

System Dynamics Modeling

Long-Term SOM Projections

A 20 year simulation of SOM in MnT and MT is presented in Figure 3. The average SOM in MnT, 3.59% (Fig. 3A), was significantly higher by 0.82% compared to MT, 2.77% (Fig. 3B). The SOM status at the 20th year (240 months) in MnT is projected to be 4.23% (Fig. 3A) while 3.13% in MT (Fig. 3B); the initial state was 3.09%. These results have a corresponding accumulation rate of 0.064% yr^{-1} in MnT and 0.007% yr^{-1} in MT. The low rate of SOM accumulation in MT is attributed to the sudden decrease in SOM upon tillage from 3.09% to 2.47% in the first 32 months (Fig. 3B). The build-up of the SOM condition in MT is projected to commence after the first three years of continuous incorporation of MLL into the soil through tillage. The SOM in MT is projected to regain its initial state after 17

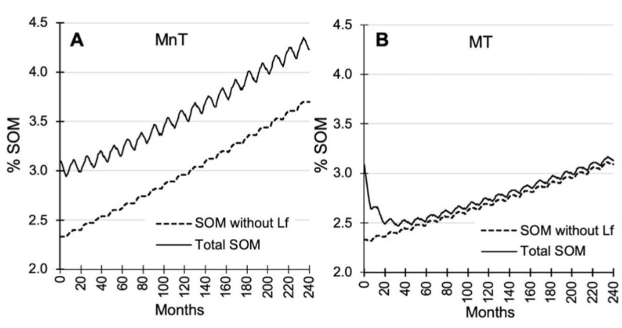

Fig. 3. A 20-year projection of SOM accumulation in non-tilled (MnT, A) and tilled (MT, B) plots as affected by the coarse (Lf) fraction. Each data point used represents an average of 26 fourteen-day simulation.

years. The estimated SOM in both MnT and MT is clearly influenced by the Lf fraction. In MnT, Lf increased SOM by 0.6% ($p < 0.01$) (Fig. 3A) whereas in tilled plots, Lf increased SOM by a slight difference of 0.07% ($p < 0.01$) (Fig. 3B). These findings are substantiated by the high SOM content in mango orchards as reported by Patricio (2014).

In spite of the increasing SOM projections in both MnT and MT, the difference between the simulated SOM increases with time. Figure 4 shows that the percentage difference of SOM in MnT over MT will reach 37% in 20 years from 14% during the first year. Even though SOM in MT is increasing, it has neither approached nor surpassed the SOM condition in MnT in 20 years.

In situ SOM Fractions as affected by Tillage

The mechanical fragmentation of MLL through tillage has no significant contribution to increase the SOM status in mango orchard during the wet and dry seasons of the in-situ experiment. This observation is plausibly explained by the fiber and lignin content which contribute to leaf toughness in the decomposition (Graca and Zimmer 2005). Mango leaf litter has low physical decomposition due to high lignin content (Musvoto et al. 2000), hence tillage did not significantly reduce the sizes of MLL comparable to Lf fraction.

Another plausible explanation is that tillage significantly decreased the collembola population during the wet season (Table 2). The reduced collembola population in MT affected its association in the SOM fractions. Table 3 shows that collembola association with Lf fraction shifted to Fn fraction upon tillage. The function of collembola in the physical decomposition

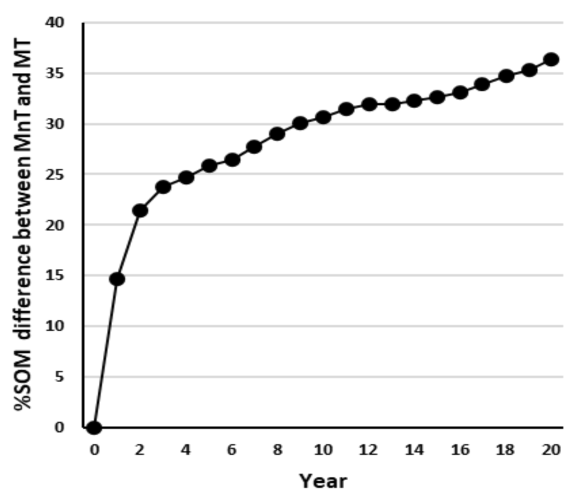

Fig. 4. Difference between the simulated SOM in non-tilled (MnT) and tilled (MT) plots.

(Chahartaghi et al. 2005) of MLL into Lf fraction was disturbed by tillage practice. Thus, the incorporation of MLL into the soil through tillage did not significantly contribute to the accrual of Lf fraction in the mango orchard. However, Yang et al. (2012) reported that the mechanical fragmentation of leaf litter with the use of machinery, supported collembola to physically break down leaf litter even with high lignin content.

From the foregoing discussion, the effect of the shift in collembola function on MLL addition through tillage and heightened bacterial activity decreased Fn fraction from 2.33% in MnT to 2.02% in MT (Table 1). The study by Garcia-Franco et al. (2015), corroborates this finding because they reported that tillage rupture soil aggregates, promoting the releases of the occluded soil-organic constituents. In addition to this, the feeding preference of collembola to humus ingestion increases when these occluded substances were freed (Ponge 2000). These newly released occluded organic particles were also exposed to mineralization by soil microorganisms. The abundance of microorganisms in the SOM fractions was highly associated with the humus, i.e. Fn fraction, which also causes C mineralization (Zanella et al. 2018). This further substantiates that the reduction of Fn fraction in MT was associated with the change in function of collembola from physical fragmentors of MLL in the Lf fraction into grazers in the Fn fraction. Carbon mineralization caused by bacterial association also reduced the Fn fraction in MT.

Twenty years of SOM Accumulation

The quantity of fragmented MLL converted into the Lf fraction is shown in Figure 5A. The model projected 45% reduction of fragmented MLL with an average of 195.38 kg yr^{-1} in MT compared to 358.84 kg yr^{-1} in MnT. Due to the minimal accrual of Lf fraction in MT, it is also expected to have lower rate of Lf recurrence (Fig. 5B). The lower rate of Lf recurrence in SOM fractions can be attributed to the mechanism of SOM persistence in any ecosystem. Schmidt et al. (2011) and Schimel and Schaeffer (2012) reported that recurrence is due to physical protection of mineral occlusion, resistance to biological decomposition, and by-product of nutrient releases. The main reasons for lower accumulation of Lf in MT over that of MnT are lower rate of MLL fraction conversion and low recurring condition of Lf.

Since the Lf inflows were reduced, it follows that Lf mineralization rate in MT was lower than that in MnT. An average rate of mineralization of 139.21 kg yr^{-1} in MT compared to 609.59 kg yr^{-1} in MnT is shown in Figure 5C. The downside of low mineralization of Lf fraction in MT is the limited release of soil nutrients. According to Strosser (2010), the Lf fraction (labile SOM) is responsible in soil nutrient releases. The low nutrient release in MT is substantiated by the significant decrease of the total N, available P and exchangeable K in MT over MnT (Table 2).

The dynamics of Lf fraction in MnT and MT is shown in Figure 5D. The abrupt drop of the Lf fraction upon tillage resulted to significant reduction of SOM in MT by 35% over that in MnT (Fig. 3B) during the 20 year simulation period. Notably, the Lf percentage status in MT decreased from 0.76% to 0.12% in the first two years of tillage (Fig. 5D), after which, Lf state in MT stabilized at 0.07% to 0.05%. The incorporation of MLL into the soil through tillage did not enhance the accrual of Lf fraction which seems to be in line with the study of Plaza et al. (2013).

With regard to Fn fraction, the transfer rate of Lf to Fn fraction in MT was much lower than that in MnT (Fig. 6A). This condition is explained by the combination of low inflow of Lf and the shift of collembola from fragmentor of Lf fraction to grazers in Fn fraction in MT. Plausibly, this is a natural response of the system to prevent the depletion of coarse particulate organic material in the Lf pool. The study of Six and Paustian (2014) explained that the turnover of Lf into Fn fraction is a natural mechanism of the decomposition process that controls and stabilizes the organic constituent of the soil. Despite having a lower Lf to Fn transfer rate in MT over MnT, the recurring rates of Fn fraction in MnT (145.28 kg

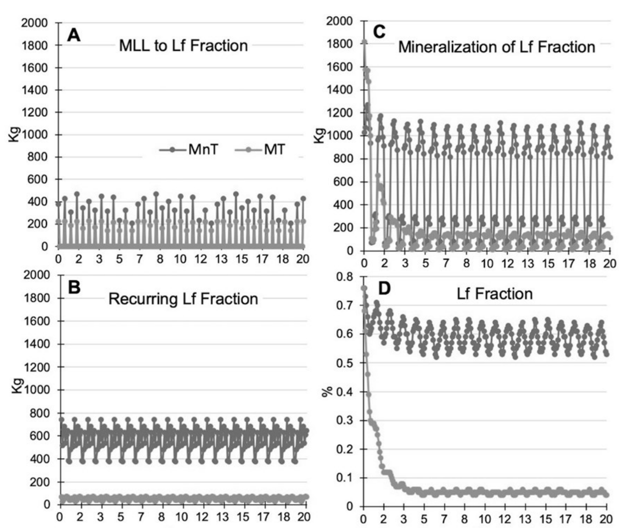

Fig. 5. Coarse fraction (Lf) accumulation in non-tilled (MnT) and tilled (MT) plots as affected by the (A) fragmentation of mango leaf litter (MLL) into Lf fraction, (B) recurrence of the Lf fraction, and (C) mineralization of Lf fraction. (D) Dynamics of Lf fraction in SOM. Each data point represents an average of 26 fourteen-day simulation.

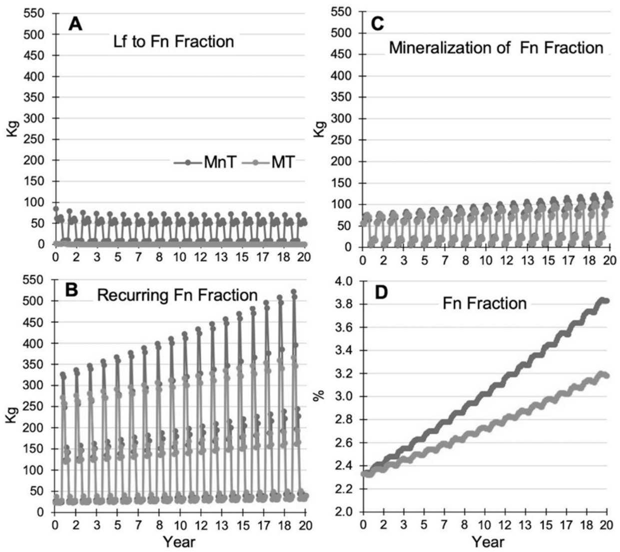

Fig. 6. Fine fraction (Fn) accumulation in MnT and MT plots as affected by the (A) Lf to Fn transfer rate, (B) recurrence of the Fn fraction, and (C) mineralization of Fn fraction. (D) Dynamics of Fn fraction in SOM. Each data point represents an average of 26 fourteen-day simulation.

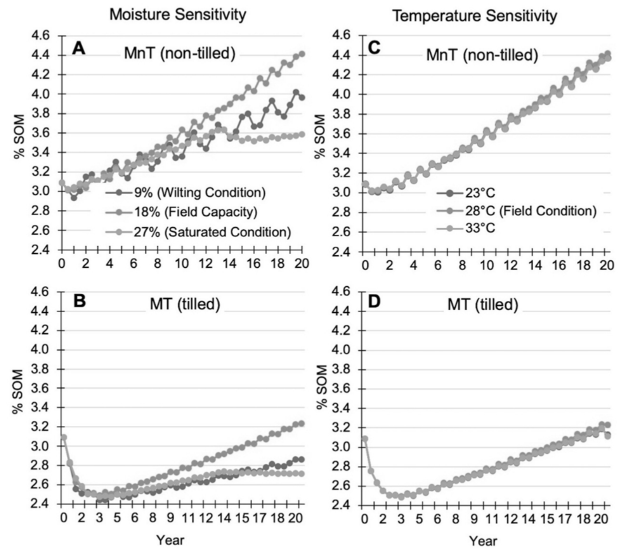

Fig. 7. Simulation of SOM accumulation in non-tilled (MnT) and tilled (MT) plots as affected by varying soil moisture (A and B) and temperature (C and D). Each data point represents an average of 26 fourteen-day simulation.

yr^{-1}) and MT (119.99 kg yr^{-1}) (Fig. 6B) were higher than the mineralization rate of 54.96 kg yr^{-1} in MnT and 49.42 kg yr^{-1} in MT (Fig. 6C).

While Fn fraction was increasing in both MnT and MT with a rate of 0.071% yr^{-1} and 0.041% yr^{-1}, respectively (Fig. 6D), the Lf fraction was decreasing (Fig. 5D). The Fn accrual in MnT and MT is attributed to higher recurring condition of Fn fraction than its mineralization rate.

Optimum Soil Moisture and Soil Temperature for SOM Accumulation

The accumulation of SOM in MnT and MT showed differential sensitivity to varying soil moisture (Fig. 7A and B) and temperature conditions (Fig. 7C and D). The accumulation of SOM in MnT is affected by varying soil moisture condition (Fig. 7A). At 9% moisture, SOM generally increased from 3.09% to 3.97 over the period of 20 years. Similarly, SOM increased from 3.09% to 4.42% at 18% moisture. At 27% moisture, SOM increased from 3.09% to 3.63% in the first 13 years, then stabilized to about 3.55% from 15 to 20 years

With MT, SOM levels dropped from 3.09% to 2.44%, 2.49% and 2.47% at 9%, 18% and 27% moisture, respectively, after three years (Figure 7B). Then, at 9% moisture, SOM increased from 2.44% to 2.86% in the next 17 years. At 18% moisture, at year 3 onwards, SOM steadily increased from 2.49% to 3.24% at year 20. The drop of SOM in the first three years is accounted by the reduction of Lf to critical level as shown in Figure 5D. At 27% moisture, SOM increased from 2.47% to 2.74%, from the 3rd year to the 14th year. Afterwards, SOM started to decline to 2.72% at the 20th year.

In sum, SOM generally increased over the period of 20 years at field capacity (18%) in both MnT and MT. Under adverse soil moisture conditions (9% and 27%) SOM was lower relative to field capacity (18%). At 9%, SOM still accumulated gradually indicating that even in drier soil condition, decomposition continues. SOM accumulation in dryer climatic regions are still possible due to the inactivity of soil microorganisms, particularly fungi, in drought condition (Yuste et al. 2010). During SOM decomposition, the fungi sequester soil carbon within their biomass, thus adding to the total SOM (Clemmensen et al. 2013).

In saturated soil, SOM began to accumulate at a low steady rate on the 13th year in both MnT and MT. The continued accumulation of organic materials with high lignin component under waterlogged soil condition slowed down the decomposition process (Chimner and Ewel 2005), leading to the buildup of undecomposed MLL. Since decomposition is slow, there is minimal addition to both Lf and Fn fractions of SOM.

For the sensitivity of SOM accumulation in varying soil temperature; 23°C (5°C lower than field condition), 28°C (field condition) and 33°C (5°C higher than field condition), the model simulation is presented in Fig. 7C and D. The accumulation of SOM in MnT mainly increased from 3.09% to 4.37% in 23°C, 4.42% in 28°C and

4.36% in 33°C (Fig. 7C). As for the MT, SOM accumulation dropped from 3.09% to 2.49% in all soil temperature levels (Fig. 7D) in the first three years. Henceforth, SOM accumulation generally increased from 2.49% to 3.13%, 2.23% and 3.11 in 23°C, 28°C and 33°C, accordingly. The accumulation of SOM neither increased in soil temperature below nor above the field condition in both MnT and MT.

The response of SOM accumulation in varying moisture and temperature conditions showed higher sensitivity in soil moisture as compared to soil temperature. This is plausibly explained by the significant correlation of collembola and bacteria to moisture rather than temperature (Table 4). As discussed, collembola aid in leaf litter decomposition through physical breakdown of Lf fraction, which contribute to SOM accumulation. The optimum soil moisture-temperature for higher SOM accumulation in MnT and MT was 18% moisture which was the field capacity at 28°C field condition.

Sustaining SOM in Tilled Mango Orchard

A strategy to circumvent the depleting Lf fraction and sustain SOM accumulation in MT is presented in Figure 8. This entails mechanical shredding of MLL before incorporating into the soil through tillage at varying compositions: 3:1 (75% shredded and 25% non-shredded), 1:1 (50% non-shredded and 50% shredded), 1:3 (25% shredded and 75% non-shredded), and no shredding. Sensitivity analyses showed that such strategy can alleviate the critical status of Lf fraction by 76% to 90% as shown in Figure 8A. Increasing the amount of shredded MLL increased the Lf fraction from a critical state of 0.07% (without shredding) to 0.29% at 1:3, 0.49% at 1:1, and 0.71% at 3:1 as shown in Figure 8A. The improved Lf accruals due to MLL shredding can sustain the high state of SOM accumulation in tilled soil of mango orchard. The result is substantiated by the findings of Yang et al. (2012), wherein the collembola has higher efficiency rate in the physical decomposition with fragmented leaf litter.

The recovery of SOM in MT through MLL shredding strategy is presented in Figure 8B. Without shredding, the status of SOM in MT is reduced from 3.09 to 2.50% within the first three years. The model projected to regain its initial state after 17 years. However, with the MLL shredding strategy using 1:3 ratio, the recovery of SOM status at its initial state is shortened by 5 years compared to no shredding. The accumulation of SOM also improved from 3.23 to 3.46% after 20 years. At 1:1 ratio, SOM accumulation rate increased further to 3.69% and SOM recovered within 7 years compared to 12 years using 1:3 ratio. At 3:1 ratio, SOM immediately recovered within two years and has a corresponding SOM accumulation of 3.93% after 20 years.

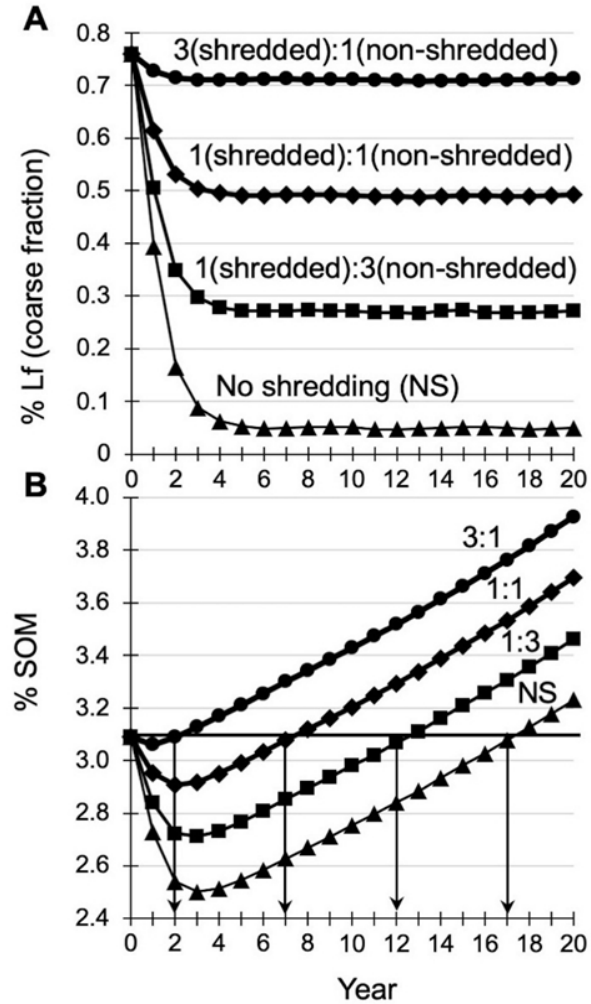

Fig. 8. Sensitivity analysis of mango leaf litter (MLL) strategy for (A) Lf fraction accrual and (B) sustained SOM accumulation using different ratios of mechanically shredded and non-shredded MLL. Arrows point to the year when the initial SOM state will be regained.

Shredding MLL does not only shorten the recovery time of SOM but also lessen the difference of SOM accumulation in MnT and MT. As shown in Figure 4, the difference of SOM accumulation in MnT over that in MT in 20 years is 37%. This can be reduced to 8% due to the improved SOM accumulation rate from 0.007% yr^{-1} (no shredding) to 0.040% yr^{-1} (3:1 ratio).

CONCLUSION

System dynamics modeling over a period of 20 years showed that SOM increased in both MT and MnT orchards. However, both Lf and Fn fractions of SOM are lower in MT than in MnT understory of mango orchard.

This finding could be explained by the decline of collembola population in MT which reduced their function in the physical decomposition of MLL into Lf fraction. In addition, carbon mineralization caused by bacterial association lessened the Fn fraction in MT compared to MnT. Overall, Fn fraction increased while the Lf fraction decreased in both MnT and MT plots. The Fn accrual is attributed to higher recurring condition of Fn fraction derived from the Lf fraction. This highlights the contribution of the Lf fraction to SOM accumulation. In MnT, Lf increased SOM by 0.6% whereas in MT, it increased by only 0.07%.

The response of SOM accumulation to varying moisture and temperature conditions showed its higher sensitivity to soil moisture than to soil temperature in both MnT and MT. The optimum SOM accumulation was observed at field capacity of 18% soil moisture and 28°C soil temperature.

To sustain the optimum level of SOM in tilled mango orchards, mechanical shredding of MLL before tilling into the soil is recommended. A ratio of 1:3 (25% shredded and 75% non-shredded) can sustain the Lf status in MT at 0.71% with 3.93% SOM, indicating that mango orchards can be used for intercropping or understory cultivation of agricultural crops. This study showed that mango leaf litter are viable sources of SOM, and thus can be used to maintain soil fertility and productivity.

REFERENCES CITED

ANGERS DA, BISSONNETTE N, LEGERE A, SAMSON N. 1993. Microbial and biochemical changes induced by rotation and tillage in a soil under barley production. Can J Soil Sci. 73(1):39–50. doi:10.4141/cjss93-004.

BANO R, ROY S. 2016. Extraction of soil microarthropods: a low cost Berlese-Tullgren funnels extractor. Int J Fauna Biol Stud. 3(2):14–17.

BARRIOS E, BURESH RJ, SPRENT JI. 1996. Organic matter in soil particle size and density fractions from maize and legume cropping systems. Soil Biol Biochem. 28(2):185–193. doi:10.1016/0038-0717(95)00110-7.

BEEDY TL, SNAPP SS, AKINNIFESI FK, SILESHI GW. 2010. Impact of *Gliricidia sepium* intercropping on soil organic matter fractions in a maize-based cropping system. Agric Ecosyst Environ. 138(3-4):139–146. doi:10.1016/j.agee.2010.04.008.

BOT A, BENITEZ J. 2005. The importance of soil organic matter: key to drought-resistant soil and sustained food and production. FAO Soils Bulletin. Food and Agriculture Organization of the United Nations. Rome, 2005.

BREVIK EC. 2013. The potential impact of climate change on soil properties and processes and corresponding influence on food security. Agriculture. 3(3):398–417. doi:10.3390/agriculture3030398.

CHAHARTAGHI M, LANGEL R, SCHEU S, RUESS L. 2005. Feeding guilds in Collembola based on nitrogen stable isotope ratios. Soil Biol Biochem. 37(9):1718–1725. doi:10.1016/j.soilbio.2005.02.006.

CHAPIN FS, MATSON PA, MOONEY HA. 2012. Principles of terrestrial ecosystem ecology. New York: Springer-Verlag.

CHIMNER RA, EWEL KC. 2005. A tropical freshwater wetland: II. Production, decomposition, and peat formation. Wetl. Ecol. Manag. 13(6):671–684. doi:10.1007/s11273-005-0965-9.

CLEMMENSEN KE, BAHR A, OVASKAINEN O, DAHLBERG A, EKBLAD A, WALLANDER H, STENLID J, FINLAY RD, WARDLE DA, LINDAHL BD. 2013. Roots and associated fungi drive long-term carbon sequestration in boreal forest. Science 339 (6127):1615–1618. doi:10.1126/science.1231923.

CORNEJO FH, VARELA A, WRIGHT SJ. 1994. Tropical forest litter decomposition under seasonal drought: nutrient release, fungi and bacteria. Oikos. 70(2):183–190. doi:10.2307/3545629

DADA EO, ARUWA CE. 2014. Microorganisms associated with urine contaminated soil around lecture theatres in Federal University of Technology, Akure, Nigeria. Int J Appl Microbiol Biotechnol Res. 2:79–85.

DAWOE EK, ISAAC ME, QUASHIE-SAM J. 2009. Litterfall and litter nutrient dynamics under cocoa ecosystems in lowland humid Ghana. Plant Soil. 330(1-2):55–64. doi:10.1007/s11104-009-0173-0.

FIEGALAN FT, RINGOR CL, MOYA TB. 2017. Collembola inoculation in soil incorporated mango leaf litter enhances decomposition for organic matter building and nutrient banking. Int J Science Res. 6:1869–1877.

GARCIA-FRANCO N, ALBALADEJO J, ALMAGRO M, MARTÍNEZ-MENA M. 2015. Beneficial effects of reduced tillage and green manure on soil aggregation and stabilization of organic carbon in a Mediterranean agroecosystem. Soil Tillage Res. 153:66–75. doi:10.1016/j.still.2015.05.010.

GRACA MAS, ZIMMER M. 2005. Leaf toughness. In: Graca MAS, Barlocher F, Gessner MO, editors. Methods to study litter decomposition: a practical guide. Dordrecht: Springer. p. 121–125.

KHAN AR. 1996. Influence of tillage on soil aeration. Journal of Agronomy and Crop Science 177: 253–259.

LU S-W, LIU C-P. 2012. Patterns of litterfall and nutrient return at different altitudes in evergreen hardwood forests of Central Taiwan. Ann For Sci. 69(8):877–886. doi:10.1007/s13595-012-0213-4.

MANZONI S, PIÑEIRO G, JACKSON RB, JOBBÁGY EG, KIM JH, PORPORATO A. 2012. Analytical models of soil and litter decomposition: solutions for mass loss and time-dependent decay rates. Soil Biol Biochem. 50:66–76. doi:10.1016/j.soilbio.2012.02.029.

MARRIOTT EE, WANDER MM. 2006. Total and labile soil organic matter in organic and conventional farming systems. Soil Sci Soc Am J. 70(3):950–959. doi:10.2136/sssaj2005.0241.

MUSVOTO C, CAMPBELL BM, KIRCHMANN H. 2000. Decomposition and nutrient release from mango and miombo woodland litter in Zimbabwe. Soil Biol Biochem. 32(8-9):1111–1119. doi:10.1016/s0038-0717 (00)00023-7.

NEEDELMAN BA, WANDER MM, BOLLERO GA, BOAST CW, SIMS GK, BULLOCK DG. 1999. Interaction of tillage and soil texture: biological active soil organic matter in Illinois. Soil Sci Soc Am J. 63 (5):1326–1334. doi:10.2136/sssaj1999.6351326x.

OU-DA-HVCD 2018. Office of the Undersecretary, Department of Agriculture, High Value Crop Development Program. Philippine Mango Industry Roadmap.

PHILIPPINE ATMOSPHERIC, GEOPHYSICAL AND ASTRONOMICAL SERVICES ADMINISTRATION – CENTRAL LUZON STATE UNIVERSITY STATION [PAGASA-CLSU]. 2017. Climatological data report from January to December, 2017. (Available at the PAGASA-CLSU station).

PARSONS SA, VALDEZ-RAMIREZ V, CONGDON RA, WILLIAMS SE. 2014. Contrasting patterns of litterfall seasonality and seasonal changes in litter decomposability in a tropical rainforest region. Biogeosciences. 11(18):5047–5056. doi:10.5194/bg-11-5047-2014.

PATRICIO JH. 2014. How much soil organic carbon is there in agricultural lands? A case study of prime agricultural provinces in Southern Philippines. AES Bioflux. 6(3).

PHILIPPINE COUNCIL FOR AGRICULTURE AND RESOURCES RESEARCH [PCARR]. 1980. Standard methods of analysis for soil, plant tissue, water and fertilizer, Los Baños, Laguna.

PLAZA C, COURTIER-MURIAS D, FERNANDEZ JM, POLO A, SIMPSON AJ. 2013. Physical, chemical, and biological mechanisms of soil organic matter stabilization under conservation tillage systems: a central role for microbes and microbial by-products in C sequestration. Soil Biol Biochem. 57:124–134. doi:10.1016/j.soilbio.2012.07.026.

PONGE J-F. 2000. Vertical distribution of Collembola (Hexapoda) and their food resources in organic horizons of beech forests. Biol Fertil Soils. 32(6):508–522. doi:10.1007/s003740000285.

PUGET P, CHENU C, BALESDENT J. 1995. Total and young organic matter distributions in aggregates of silty cultivated soils. Eur J Soil Sci. 46(3):449–459. doi:10.1111/j.1365-2389.1995.tb01341.x.

SCHEER MB. 2009. Nutrient flow in rainfall and through fall in two stretches in an Atlantic Rain Forest in southern Brazil (in Portuguese). Floresta. 39:117–30.

SCHIMEL JP, SCHAEFFER SM. 2012. Microbial control over carbon cycling in soil. Front Microbiol. 3. doi:10.3389/fmicb.2012.00348.

SCHMIDT MWI, TORN MS, ABIVEN S, DITTMAR T, GUGGENBERGER G, JANSSENS IA, KLEBER M, KOGEL-KNABNER I, LEHMANN J, MANNING DAC, ET AL. 2011. Persistence of soil organic matter as an ecosystem property. Nature. 478(7367):49–56. doi:10.1038/nature10386.

SIX J, PAUSTIAN K. 2014. Aggregate-associated organic matter as an ecosystem property and a measurement tool. Soil Biol Biochem. 68:A4–A9. doi:10.1016/j.soilbio.2013.06.014.

STROSSER E. 2010. Methods for determination of labile soil organic matter: an overview. J Agrobiol. 27(2):49–60. doi:10.2478/s10146-009-0008-x.

TALEMOS S, SEBSEBE D, ZERIHUN W. 2018. Litterfall dynamics in Boter-Becho forest: moist evergreen montane forests of southwestern Ethiopia. J Ecol Nat Environ. 10(1):13–21. doi:10.5897/jene2017.0648.

TROST B, PROCHNOW A, DRASTIG K, MEYER-AURICH A, ELLMER F, BAUMECKER M. 2013.

Irrigation, soil organic carbon and N_2O emissions. A review. Agron Sustain Dev 33:733–749.

VON LÜTZOW M, KÖGEL-KNABNER I, EKSCHMITT K, FLESSA H, GUGGENBERGER G, MATZNER E, MARSCHNER B. 2007. SOM fractionation methods: Relevance to functional pools and to stabilization mechanisms. Soil Biol Biochem. 39(9):2183–2207. doi: 101016/j.soilbio.2007.03.007.

WALKLEY A, BLACK IA. 1934. An examination of the Degtjareff method for determining soil organic matter and proposed modification of the chromic acid titration method. Soil Sci. 37(1):29–38. doi:10.1097/00010694-193401000-00003.

WANDER M. 2004. Soil organic matter fractions and their relevance to soil function. In: Magdoff F, Weil RR, editors. Soil organic matter in sustainable agriculture. USA:CRC Press. p. 67-102.

YANG X, YANG Z, WARREN MW, CHEN J. 2012. Mechanical fragmentation enhances the contribution of Collembola to leaf litter decomposition. Eur J Soil Biol. 53:23–31. doi:10.1016/j.ejsobi.2012.07.006.

YUSTE JC, PEÑUELAS J, ESTIARTE M, GARCIA-MAS J, MATTANA S, OGAYA R, PUJOL M, SARDANS J. 2010. Drought-resistant fungi control soil organic matter decomposition and its response to temperature. Glob Change Biol. 17(3):1475–1486. doi:10.1111/j.1365-2486.2010.02300.x.

ZANELLA A, PONGE JF, FRITZ I, PIETRASIAK N, MATTEODO M, NADPOROZHSKAYA M, JUILLERET J, TATTI D, LE BAYON RC, ROTHSCHILD L, MANCINELLI R. 2018. Humusica 2, article 13: para humus systems and forms. Appl Soil Ecol. 122:181–199.

ZHANG H, YUAN W, DONG W, LIU S. 2014. Seasonal patterns of litterfall in forest ecosystem worldwide. Ecol Complex. 20:240–247. doi:10.1016/ j.ecocom.2014.01.003.