Original Research Article

Evaluating the Impact of Integrated Nutrient Management Practices on Land Productivity, Crop Residue Decomposition and Abundance of Soil Organisms in a Banana Plantation in Sri Lanka

ABSTRACT

The fertilization practices heavily influence the decomposition rate of organic materials added to soil. Hence, the nutrient management strategies that aim to improve crop yields may not necessarily support organic carbon accumulation in soil and overall soil fertility. This study investigated how land productivity, crop residue decomposition and diversity of soil organisms were affected by the combined use of chemical fertilizers (CF) and poultry manure (PM) in a banana plantation in Buttala, Sri Lanka. Banana yield, soil properties and decomposition of crop residues were studied in six treatments as, CF1+PM1, CF1+PM2, CF1+PM3, CF2 +PM1, CF2+PM2, and CF2+PM3. CF1 and CF2 correspond with 75% and 100% of recommended CF application rate. PM1, PM2 and PM3 correspond with PM application rates of 0, 2.5 and 5 kg/plant. Crop residue decomposition was assessed using litter bags containing two litter materials as banana pseudo-stem pieces and banana leaves and placed at two depths (surface and at 7.5 cm depth). Litter bags were recovered at 17, 31 and 45 days after placement (DAP) and weight loss of crop residues was determined. The application of poultry manure significantly increased ($P<0.01$) banana yield at first harvest and decreased ($P<0.1$) bulk density. Type of material and time of exposure to decomposition had significant effects ($P<0.05$) on litter decomposition but depth of placement and nutrient management strategy had no significant effect ($P>0.05$) on decomposition. By 45 DAP pseudo-stems were degraded more than leaves (67.47±13.99 % and 46.90±5.76 %, respectively). The abundance of culturable bacteria and cellulose decomposers in soil and the abundance of soil fauna in decomposing litter were significantly ($P<0.1$) increased with the PM application to soil. In conclusion, in the studied banana plantation, incorporation of PM in nutrient management increased land productivity and had positive impact on some soil properties, which are important determinants of soil fertility but did not register any effects on crop residue decomposition during the study period.

Keywords: Decomposition, Nutrient management practices, Soil microorganisms, Litter bag experiment, Soil fertility

1. INTRODUCTION

World population which is expected to become 9.7 billion by 2050, will add an extra pressure on agricultural production systems in terms of addressing food security and maintaining agricultural sustainability [1]. It has been projected that the urban population would reach 6 billion by 2045, and this would contribute to reduce productive arable lands [2]. This has been identified as one major reason for malnourishment and increase the risk of the non-communicable diseases across the world [3]. In order to increase the productivity of arable lands, one strategy is to improve the soil organic carbon (SOC) content [4], which highly depends on the agronomic practices that are being practiced in the land [5]. Carbon cycle in the soil is very much linked with other nutrient cycles [6]. The rate of decomposition of organic materials and accumulation of SOC are heavily influenced by fertilization practices. Hence, when experimenting on different nutrient management strategies targeting to improve crop yields, it is important to investigate how these strategies impact on the organic material decomposition and SOC pools.

During decomposition, organic materials break down and release nutrients to soil and carbon dioxide like gases to atmosphere [7]. Residue quality characteristics like carbon to nitrogen (C:N) ratio, chemical composition of crop residues like cellulose, hemicellulose, lignin and polyphenol contents [8,9,10,11], diversity of decomposer organisms and physicochemical conditions of the environment [7] like factors affect the rate of organic material decomposition in soil. In addition, the particle size of crop residues, loading rate and application method of crop residues to soil affect the decomposition process and SOC [10,11,12]. As a common practice in banana plantations, farmers incorporate banana pseudo-stems and leaves to the surface of soil after every harvest [13]. Soil faunal activity is the main factor that is responsible for the nutrient release from banana residues [13]. According to Chou et al. [14], SOC content positively correlated with microbial diversity, while the abundance of heterotrophic bacteria, free living nitrogen fixing bacteria, tri-calcium phosphate solubilizing bacteria and proteolytic bacteria were higher in long-term organically managed soils compared to the long-term conventionally managed soils.

Organic and synthetic chemical fertilizers increase the amount of plant available nutrients in soil to different degrees based on the type of fertilizer, and lead to changes in the structure and functions of soil microbial communities [15,16,17]. In integrated nutrient management approach, synthetic chemical fertilizers are used together with organic fertilizers to cater to crop nutrient demand. Integrated nutrient management is known to increase crop yield while decreasing the reliance on synthetic chemical fertilizer requirement [18]. Integration of organic fertilizers and organic soil amendments in nutrient management strategies could result in additional benefits like improvements in soil fertility status. Poultry manure, originating from broiler and layer chicken farms, is a low-cost organic fertilizer popularly used in crop cultivation in Sri Lanka [19]. However, our understanding on the impact of using poultry manure in integrated nutrient management strategies on crop residue decomposition and the dynamics of decomposer communities is limited.

Cultivating banana targeting the export market is an expanding agro-industry in Sri Lanka. However, inherent soil fertility and productivity of the lands available for commercial scale banana cultivation is moderate or poor. Therefore, the banana growers are compelled to make a significant investment on their lands to increase productivity and to obtain export quality harvest sustainably. In addition, eco-certifications considered by the consumers in competitive export market force the growers to adopt sustainable nutrient management practices with low carbon footprint. Thus, some commercial scale banana growers have started integrated nutrient management practices. This study was conducted to investigate how the integrated nutrient management practiced with different rates of synthetic chemical fertilizers and poultry manure would influence on crop productivity, residue decomposition rate and soil organisms involved in organic material decomposition in a banana plantation in Sri Lanka.

2. MATERIALS AND METHODS

2.1 Site Description

This study was conducted in a two-year-old banana field of Dole Lanka (Pvt) LTD, in Buttala, (6° 41’ 57.35” N 81° 15’ 0.50” E) Sri Lanka. The site is located in the DL1a Agro-ecological region of the Dry zone - Low country (annual rainfall of 1300 mm), and the prominent soil type in the region is Rhodustalfs [20]. The extent of the experimental site is about 1 ha and the field comprised of nearly 2500 of Cavendish banana plants in 18 plots arranged in a completely randomized block design (RCBD) with three blocks. Each block consisted of six treatments of different nutrient management practices (T1 to T6) as all possible combinations of two rates of farm recommended synthetic chemical fertilizer (CF) applications, and three rates of poultry manure (PM) applications. The treatments were CF1 + PM1 (T1), CF1 + PM2 (T2), CF1 + PM3 (T3), CF2 + PM1 (T4), CF2 + PM2 (T5), and CF2 + PM3 (T6); where CF1 and CF2 correspond with 75% and 100% of farm recommended CF application rates, and PM1, PM2 and PM3 correspond with PM applications of 0 kg, 2.5 kg and 5 kg per plant. PM had been applied two weeks before planting and 6 months after the crop establishment. As CF application, all plants received Sulfate of Ammonia (SA) and Di-ammonium Phosphate (DAP) as the basal dressing and as top dressing two weeks after planting. Then the application of SA and DAP to soil was continued as top dressings at 3 weeks interval until 75% of the plants reached flowering stage. After that SA, DAP, Muriate of Potash (MOP), Calcium Sulfate, and Kieserite had been applied to soil, and Borate and Zinc sulfate had been applied as foliar sprays at monthly interval.

Banana plants were planted in double hedge rows with two drip irrigation lines separately for each row. Each plot of the size 400m^2 contained three double hedge rows with 140 number of plants. Treatments were allocated perpendicular to the slope gradient of 3 %. The treatments were initiated and maintained from the 1st day of establishment of plants. The *in-situ* crop residue decomposition study using litter bags was commenced nearly one and half years after planting banana and carried over a period of one and half months. The average temperature during this period was 27±5.4 °C.

2.2 Litter Bag Experiment

Litter decomposition study was carried out with a litter bag study [21]. Litter bags of the size of 10 cm × 10 cm were prepared using nylon mesh (1 mm × 1 mm openings) on one side and white color polyester clothing material on the other side. It was expected that nylon mesh would facilitate the exposure of litter material for soil fauna with body size (diameter) less than 1.41 mm as well as microorganisms, and polyester clothing material would facilitate the entrance of only microorganisms. When placing the litter bags in soil, the nylon mesh side was arranged to face down, while the polyester clothing material side facing up in order to avoid the migration of clay from upper soil layer into the litter bag. Two types of litter materials, i.e. banana pseudo-stem and banana leaves, were filled into litter bags separately as 10±2 g fresh weight equivalent of material per bag. When using banana pseudo-stems, two pieces (each 7 cm × 2.5 cm size) were filled into one bag. When using banana leaves, 12 pieces of leaves (7 cm × 2.5 cm pieces) and one mid rib piece were filled into a bag. From each litter type 324 bags were prepared and the fresh weight of material in each bag was recorded. The moisture factor of the two litter materials were determined separately in three replicates to estimate the dry weight of the materials laced in litter bags. Three places in between the double hedge row of banana were randomly selected per plot to place the litter bags at surface (under the mulch) and at 7.5 cm depth. At each selected location at each soil depth, three litter bags from each litter type were placed horizontally with nylon mesh side facing down. Accordingly, 36 litter bags (18 pseudo-stems and 18 leaves) were placed per plot (one replicate of a treatment). Three litter bags from each litter type at each soil depth were recovered at three time points, i.e. 17, 31 and 45 days after placement (DAP) to determine the mass loss due to decomposition.

After recovering litter bags from soil, the partially decomposed litter was observed for the presence of macro- and meso-fauna visible to the naked eye. A rank from 1-3 was assigned based on the presence of visible organisms as 1 being the lowest and 3 being the highest presence. Then visible soil fauna and the adhered soil particles in partially decomposed litter materials were removed by hand and by density separation, respectively. Then the material was oven dried at 65 °C for 72 hours and dry weight of the litter material was recorded using OHAUS PR224 analytical balance. The percent mass loss was calculated using the dry mass of materials placed in the litter bag and mass of partially decomposed material recovered from the litter bag after retrieving from soil [21].

2.3 Soil Sampling and analyses

Soil samples were collected at 0-15 cm depth as disturbed samples using an auger. Three soil samples were collected per plot at close proximity to the three locations selected to place the litter bags in a given plot. At each location, two augured soil samples were combined to obtain a representative sample of the location. Each soil sample was divided into two parts, stored separately as fresh soils (at 3 °C) and air-dried soils. In addition, two soil core samples were collected at 7.5 cm depth at two locations per plot in close proximity to the places where litter bags were placed. The core samples were used to determine the bulk density (BD), gravimetric water content (GWC) and volumetric water content (VWC).

From the 54 disturbed soil samples collected from the 18 plots (6 treatments with three replicates), 36 samples were randomly selected as two samples per plot to proceed with microbiological and chemical analyses. Total fungi, total bacteria and cellulose decomposers were cultured following serial dilution with spread plate technique, using Rose Bengal agar with streptomycin, Tryptic Soy Agar and Cellulose agar, respectively, as the selective growth media. Soil chemical properties like soil pH, electrical conductivity (EC), available nitrogen (AN), and soil organic carbon (SOC) as well as soil physical properties such as clay content (CC), BD, GWC and VWC were determined using standard methods. Soil pH and EC were measured in a soil to distilled water (1:5) suspension using an Eutech CyberScan pH 510 Bench series pH meter and an Eutech Con 2700 series EC meter, respectively. Available nitrogen in fresh soil samples were extracted using 1M KCl and subjected to Kjeldahl distillation and titration to determine the AN in soil [22]. In order to determine the SOC, air-dried soil samples were ground and passed through 0.5 mm sieve. Organic carbon was measured using a colorimetric method [23]. In here, 0, 0.5, 1.0, 1.5, 2.0, 3.0, 3.5 % glucose solutions were prepared as standard calibration series and absorption was measured at 600 nm using a SHIMADZU 1900i UV-Visible spectrophotometer. BD, GWC and VWC were determined at 7.5 cm depth using a 5 cm height core sampler. Fresh weights, dry weights and the volume of the core samples were measured [24]. In order to find the CC, air-dried soil samples were pre-treated using hydrogen peroxide and 5% sodium hexa-meta phosphate solution. Standard ASTM no. 152H hydrometer with Bouyoucos scale in grams per liter was used to take measurements at different time intervals [25].

2.4 Yield data

Yield data related to the plots were obtained from the farm records during the period July, 2022 to February, 2024. During that time period, 2 harvests had been taken from 25 judgmentally selected representative plants from each plot. The yield was calculated as kg of bunches per hectare separately for the two harvests.

2.5 Statistical Analysis

The SPSS software was used to analyze data statistically. Data on the abundance of microorganisms was log transformed before using in statistical analyses. All the data were initially checked with Shapiro-Wilk test to examine the normality of the data. Also, their Skewness and Kurtosis were tested to check whether the data match with basic assumptions of Analysis of variance (ANOVA). The effect of CF rates and PM rates on yield, and several physical, chemical and biological properties determined were assessed using a two-way ANOVA considering CF and PM rates as the main factors. ANOVA with three factor factorial design was performed first to find the significance of litter material type, depth of placement of litter bags and the time of exposure of litter materials in soil on decomposition status (percent mass loss) of the crop residues. Then using data for each litter material type at each time-point, two factor factorial analysis in ANOVA was performed using treatment and depth of placement of litter bags as the main factors to find the significance of nutrient management strategy on decomposition status of litter. Visible organisms' data were analyzed using Kruskal-Wallis test to check the significance of treatment effect on the macroorganisms' abundance in litter bags. The significance of the main effects and interactive effects were determined at 90% and 95% confidence levels ($p=0.1$ and $p=0.05$, respectively). Mean separation was performed using Duncan's multiple range test at p=0.05. Correlations between the analyzed properties were determined using Pearson's correlation analysis at $p=0.05$.

3. RESULTS AND DISCUSSION

3.1 Land productivity

The soil in the experiment site was slightly acidic and low in SOC content (Table 1). Soil texture was clay to clay loam and GWC was 0.27 g/g while VWC was 0.33 cm^3/cm^3. Soil conditions in the land was not that of a typical soil profile under natural vegetation in the region because the land preparation for banana cultivation has disturbed the soil to a great extent. Soil become excessively wet during rainy season and dry and hard during dry season making moisture management a great challenge. Therefore, deep trenches have been cut in equal distances to support drainage and drip irrigation has been used for efficient water management. The top soil of the field at present consists mostly of soil from previous sub-soil horizons (e.g. AB and B) that resulted from land preparation constructing the trenches. Therefore, the inherent fertility status of soil is poor to moderate in this field. Based on target yield and soil fertility characteristics the farm uses its own site-specific fertilizer recommendation for the cultivation of banana.

Nutrient management strategy is an important determinant of crop yield and land productivity. In the present study, banana yield at first harvest was significantly affected by the PM application rate ($P<0.05$) but not by the CF application rate ($P>0.05$) used (Table 1). However, the second harvest was not significantly affected ($P>0.05$) by the CF or PM application rates. Reducing CF usage by 25% from the recommended quantity for growing banana in the studied farm did not significantly reduce ($P>0.05$) yield (Table 1). However, in comparison to applying CF alone, the application of PM with CF as an integrated nutrient management practice resulted in significantly higher ($P<0.05$) yield at the first harvest (Figure 1). The average yield registered for 0 kg PM, 2.5 kg PM and 5 kg PM/ plant rates during the second harvest were 54,167±3,181 kg/ha, 56,979±6,167 kg/ha, and 56,563±4,724 kg/ha, respectively. Although the yield was not significantly affected by PM application rate in the second harvest, yield was higher with PM+CF application than when applying CF alone. Previous studies have recommended the application of animal manures together with CF in nutrient management programs for commercial scale Cavendish banana cultivation targeting to achieve high yields [26, 27]. According to the results, instead of using CF at recommended rate alone, applying at least 2.5 kg of PM per plant with 75% of CF (T2) in integrated nutrient management would help to increase land productivity (Table 1). Chalise et al. [26] recommended the application of farm yard manure at the time of planting and 3rd, 5th and 7th month after planning at 5 kg/ plant rate to achieve high quality and quantity of banana yield. The yield of Cavendish banana in this study was in the range reported in literature under tropical climatic conditions [26, 27].

Results indicate that some soil related constraints limiting crop productivity in this banana plantation may have been alleviated with the application of the PM. Previous studies also support that application of PM increased crop yield [18,27,28,29]. Hoover et al. [29], further explained that PM applications has increased the organic matter and micro nutrient contents in the soil. According to Boateng et al. [18], application of PM had led to change the soil properties that facilitated a conducive environment for the plant growth and activity of micro- and macro-fauna. Ayeni et al. [30] reported that plant uptake of N, P, K, Ca, Mg, Zn, Fe and Cu were increased in maize with PM applications. Therefore, in the present study, the application of PM may have improved the overall soil fertility compared to the application of CF alone and thereby enhanced the crop productivity.

3.2 Soil properties and parameters

The nutrient management strategies are known to affect soil properties [18,31]. None of the soil properties tested in this study were affected by integrated nutrient management practices except BD (Table 1). The rate of PM application significantly influenced ($P<0.1$) BD of soil (Table 1 and Figure 2). According to Boateng et al. [18], application of PM with high organic carbon content, increased the water retention ability of soil. Also, they observed that the application of PM, ultimately resulted in a reduction in soil BD benefitting plant growth. Increase in SOC and nutrient availability in soil with the application of PM has been observed in previous studies [18,28]. The present study was conducted only after one and half years since implementing the nutrient management strategies and one year after the last PM application event. During the study period only two PM application events were practiced. Therefore, the short period and low frequency of PM application may be inadequate to make significant changes in soil properties in the studied fields.

Table 1: The effect of six different combinations of chemical fertilizers (CF) and poultry manure (PM) application rates on bunches the first harvest yield of banana and soil physical and chemical properties (BD – bulk density; GWC – gravimetric water content; VWC – volumetric water content; CC – clay content; EC – electrical conductivity; AN – available nitrogen; SOC – soil organic carbon). The values are presented as mean ± standard deviation.

Treatment[1]	**Yield (Bunches kg/ha)**	**BD (Mg/m^3)**	**GWC (g/g)**	**VWC (cm^3/cm^3)**	**CC (%)**	**pH**	**EC (dS/m)**	**AN (mg/kg)**	**SOC (%)**
T1	56605±6537	1.32±0.04	0.27±0.00	0.35±0.01	33±2.1	5.61±0.43	0.11±0.03	72.63±6.94	1.18±1.04
T2	60500±7820	1.18±0.07	0.29±0.04	0.34±0.02	39±5.0	6.03±0.38	0.10±0.00	85.01±13.72	1.81±0.85
T3	59548±7354	1.21±0.04	0.27±0.02	0.33±0.03	38±6.2	5.90±0.01	0.11±0.02	85.79±12.31	1.42±0.93
T4	57568±6551	1.25±0.10	0.26±0.02	0.32±0.02	36±3.2	5.57±0.39	0.12±0.02	75.69±10.26	1.55±0.43
T5	60843±6133	1.22±0.11	0.28±0.03	0.33±0.03	37±2.9	5.62±0.72	0.09±0.04	83.53±19.67	1.29±0.48
T6	62628±6709	1.19±0.05	0.27±0.03	0.32±0.03	35±6.8	5.42±0.23	0.11±0.05	71.80±3.24	1.26±0.20
Significance of main factors and their interactions (*P*)[2]									
CF rate	0.130	0.578	0.305	0.117	0.602	0.155	0.925	0.354	0.751
PM rate	**<0.001**[**]	**0.066**[*]	0.146	0.805	0.192	0.635	0.553	0.202	0.828
CF rate × PM rate	0.625	0.343	0.790	0.577	0.310	0.641	0.802	0.283	0.507

[1] T1 = 75% CF + 0kg PM, T2 = 75% CF + 2.5kg PM, T3 = 75% CF + 5kg PM, T4 = 100% CF + 0kg PM, T5 = 100% CF + 2.5kg PM, T6 = 100% CF + 5kg PM. Please note PM was applied at mentioned quantity as kg/plant twice since crop establishment.

[2] *P*-value indicating the significance of main factors and their interaction in two-way ANOVA for each measured variable.

**Indicate the significance at 95% confidence interval.

*Indicate the significance at 90% confidence interval.

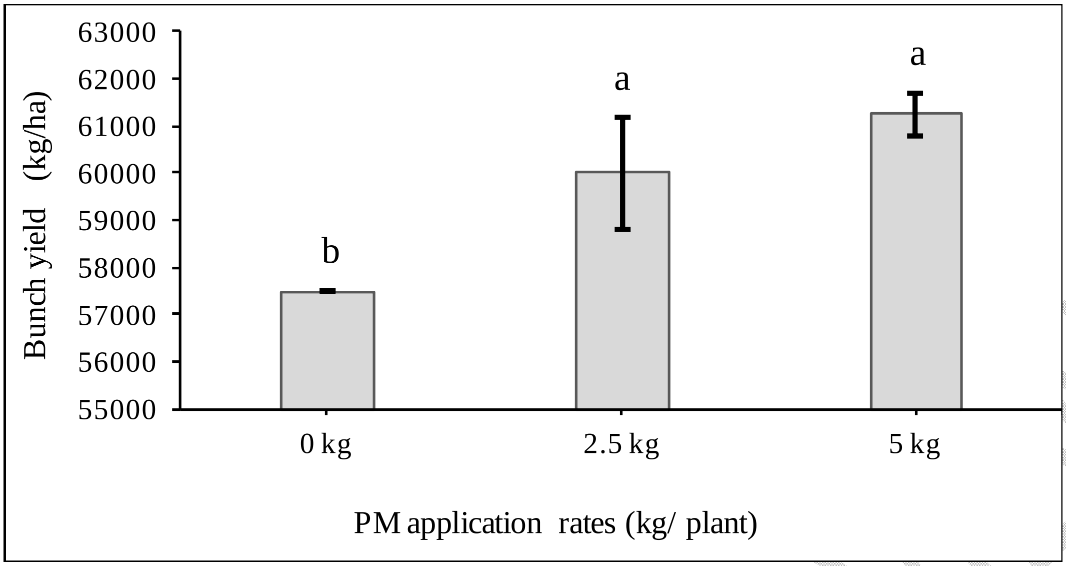

Figure 1: Mean bunch yield of banana at the first harvest as affected by different rates of poultry manure (PM) applications. Bars followed by same lowercase letters indicates that there is no significant difference between treatments at *P*=0.05. Error bars indicate standard deviation.

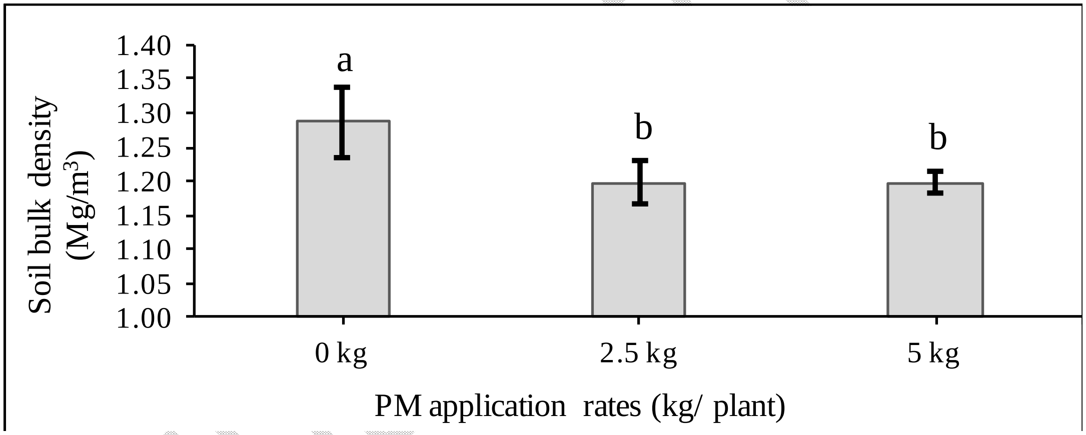

Figure 2: Mean values of bulk density according to the different rates of PM applications. Bars followed by same lowercase letter indicates there is no significant difference at *P*=0.1. Error bars indicate standard deviation.

Combined applications of different rates of CF and different rates of PM applications did not significantly affect (*P*>0.05) the abundance of total culturable fungi, bacteria and cellulose decomposers (Table 2). However, the abundance of cellulose decomposers and total bacteria were significantly increased (*P*<0.1) when PM application rate was increased (Table 2 and Figure 3). Calderon et al. [32] also observed a significant increase in cellulolytic bacteria belong to orders of Myxococcales and Xanthomonadales and increase in bacterial population with PM applications. They further explained that, compared to PM untreated soils, PM treated soils contained more organisms that help in organic matter decomposition and nutrient cycling. Li et al. [33], stated that carbon cycling is one of the vital roles of the members of Myxococcales who are important as micro-predators in soil. Present study did not show changes in the diversity of dominant morphotypes of colony forming units (CFU) of culturable populations in response to nutrient management practices.

The presence of soil fauna was significantly increased (*P*<0.05) with the application of different rates of poultry manure. According to an experiment done by Ashworth et al. [34], earthworm population was significantly increased with PM applications. In the present study, the last event of PM application was nearly one year before soil sampling for determining the biological properties. Therefore, it is interesting to note that although the PM application did not make a significant change in soil physico-chemical properties except for BD (Table 1), its impact on biological properties was still prominent even after one year since the last PM application (Table 2).

Table 2: The abundance of total culturable fungi, bacteria and cellulose decomposers in soil and the presence of soil fauna in litter bags placed in banana cultivated soil treated with different rates chemical fertilizers (CF) and poultry manure (PM). Values are presented as mean ± standard deviation.

Treatment[1]	**Total Fungi (Log_{10} CFU/g dry soil)**	**Total Bacteria (Log_{10} CFU/g dry soil)**	**Cellulose Decomposers (Log_{10} CFU/g dry soil)**	**Presence of soil fauna[2]**
T1	3.43±0.13	7.41±1.25	5.27±0.20	1
T2	3.26±0.17	8.36±1.28	5.93±0.23	2
T3	3.22±0.33	9.09±0.52	5.95±0.27	3
T4	3.39±0.08	8.34±0.62	5.47±0.22	1
T5	3.00±0.41	9.28±2.96	5.43±0.42	3
T6	3.07±0.31	10.60±1.10	6.14±0.81	3
Significance of main factors and their interactions (*P*)[3]				
CF rates	0.317	0.164	0.728	0.151
PM rates	0.221	**0.071***	**0.081***	**0.001****
CF rate × PM rate	0.800	0.674	0.414	

[1] T1 = 75% CF + 0kg PM, T2 = 75% CF + 2.5kg PM, T3 = 75% CF + 5kg PM, T4 = 100% CF + 0kg PM, T5 = 100% CF + 2.5kg PM, T6 = 100% CF + 5kg PM. Please note PM was applied at mentioned quantity as kg/plant twice since crop establishment.

[2] 1 = Poor, 2 = Medium and 3 = High occurrence.

[3] *P*-value indicating the significance of main factors and their interactions on measured variables.

* Indicate the significance at 90% confidence interval.

**Indicate the significance at 95% confidence interval.

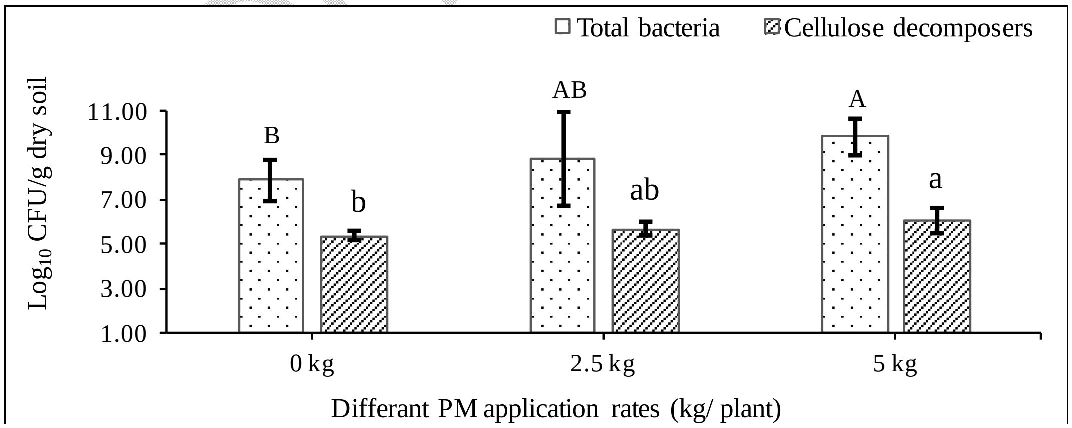

Figure 3: Mean abundance of total bacteria and cellulose decomposers in soil as affected by different rates of PM applications. Bars followed by same letters for each variable indicates that there is no significant difference between treatments at *P*=0.1. Error bars indicate standard deviation.

Visual observations of the decomposing crop residues recovered from the litter bags indicated that the meso- and macro-fauna recovered from the partially decomposed crop residues in litter bags were influenced by the application of PM. Organisms living in association with decomposing crop residues in the litter bag is an indicator of the abundance of soil fauna involved in organic material decomposition in the studied soil. According to the observations, various types of soil fauna in different size categories were seen. Some of them were larger than the holes in nylon mesh, indicating that they may have entered litter bags at their initial developmental stages and grown larger while feeding on crop residues placed in the litter bag. Ngosong et al. [35] observed a significant difference in macro-organism abundancy with different rates of PM applications. Some environmental conditions like temperature and moisture content as well as the quality and quantity of available food determine the growth and hatchability of earthworms [36]. Previous research indicate that macro-organisms play a vital role in decomposition than microorganisms in tropical environments [37].

3.3 Crop residue decomposition

The results from litter bag study indicated that the decomposition of crop residues was significantly affected ($P<0.05$) by the type of litter material (crop residue) and the time of exposure of residue for decomposition in soil than the depth of placement ($P>0.05$) in soil (Table 3). The depth of placement had a significant effect ($P<0.05$) on decomposition of banana pseudo-stems only at 17 days into decomposition, while materials left on soil surface decomposed more than the materials places at 7.5 cm depth (Figure 4). However, the decomposition of banana crop residues was not significantly affected ($P>0.05$) by the nutrient management strategy (Figure 4). The standard deviation values were very high due to the high variability in the field.

Table 3: Summary statistics of the effect of time allowed for decomposition (time points: 17, 31 and 45 DAP), depth of placement (surface and 7.5cm depth) and type of crop residue (material types: banana stems and banana leaves + mid rib) on the mean weight loss percentages of crop residues in a banana cultivated soil.

Material Type	Depth of Placement (DOP)	Time point	Mean weight Loss %
Banana stems	Surface	17 DAP	34.87±11.14
Banana stems	Surface	31 DAP	55.53±10.57
Banana stems	Surface	45 DAP	65.62±11.46
Banana stems	7.5cm depth	17 DAP	28.76±10.49
Banana stems	7.5cm depth	31 DAP	57.74±12.01
Banana stems	7.5cm depth	45 DAP	69.33±17.27
Banana leaves + mid rib	Surface	17 DAP	24.28±3.67
Banana leaves + mid rib	Surface	31 DAP	40.55±5.41
Banana leaves + mid rib	Surface	45 DAP	44.98±6.91
Banana leaves + mid rib	7.5cm depth	17 DAP	24.05±3.61
Banana leaves + mid rib	7.5cm depth	31 DAP	37.74±5.11
Banana leaves + mid rib	7.5cm depth	45 DAP	48.82±6.87
Significance of main factors and their interactions (*P*)[1]			
Litter type			**<0.001****
Depth of placement			0.938
Time point			**<0.001****
Litter type × Depth of placement			0.897
Litter type × Time point			**<0.001****
Depth of placement × Time			0.090
Litter type × Depth of placement × Time point			0.227

[1] The significance of main factors in three-way ANOVA for weight loss.

** Indicate the significance at 95% confidence interval.

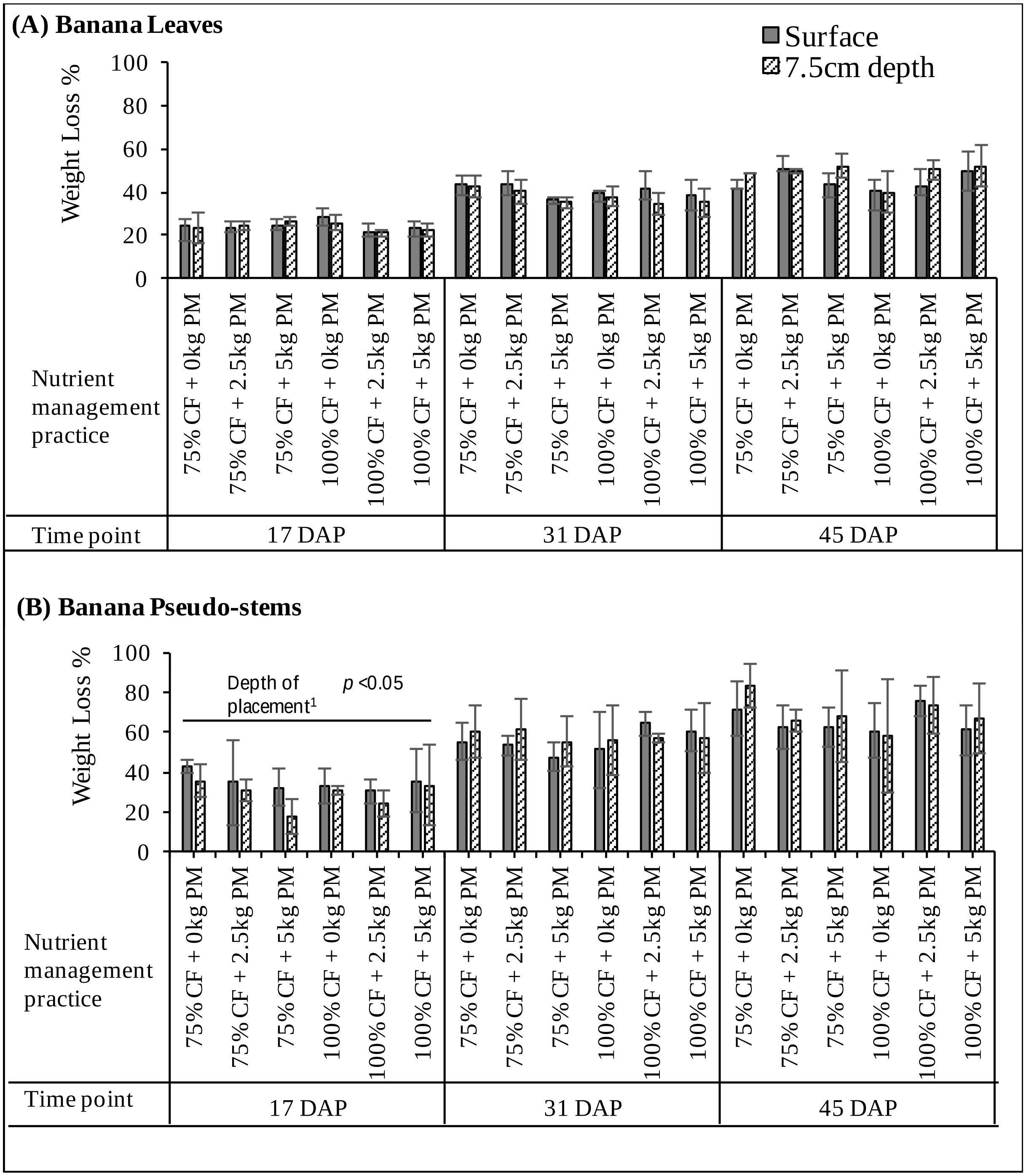

Figure 4: Mean weight loss percentages of (A) banana leaves and (B) banana pseudo-stem pieces placed at two depths (surface and at 7.5 cm depth) in a banana cultivated field subjected to six treatments as all possible combinations of two rates of CF applications (100% and 75% of recommendation) and three rates of PM applications (0, 2.5 and 5 kg/ plant). Litter bags were recovered at three time points after placement (17, 31 and 45 DAP). Error bars indicate standard deviation.

[1] The effect of depth of litter bag placement was significant (*P*<0.05) on decomposition of banana pseudo-stems at 17 DAP.

Soil organisms seem to decompose banana pseudo-stems faster compared to leaves. This may be mainly because of the high cellulose content and high moisture content in banana pseudo-stems than those in banana leaves [13,38,39]. In this study, moisture contents observed in two litter materials, i.e. banana pseudo-stems and leaves were 94% and 76% respectively. Lignin and nitrogen contents in litter materials are major governing factors of the decomposition of litter because these two factors influence the palatability of the material to soil fauna [40]. A previous study reported that the litter materials containing high nitrogen are susceptible for rapid decaying than the litter materials containing low nitrogen [40]. It has been noted that C:N ration of banana pseudo-stems is around 31; whereas, C:N ratio of banana leaves is about 54 [41,42].

According to previous observations, litter materials that were incorporated into the soil were more degraded than litter materials kept on the surface because of the proper contact with the soil, and the high availability of moisture for the decomposition process, which may accelerate decomposition [43,44]. However, results from the present study were not consistent with this observation. In contrast to the previous studies, the pseudo-stems kept on surface were more degraded compared to the ones kept at 7.5 cm depth at 17 DAP in the present study (Figure 4). The reason for this may be the high availability of nutrients for the soil organisms at the surface of the soil due to the surface application of fertilizers. It was noted that the CF and PM had been applied to the surface of the soil and crop residues were also left on the surface as a mulch. Therefore, the conditions might facilitate high biological activity on the surface of the soil just below the mulch layer.

3.4 Interrelationships between measured variables

Correlation analysis revealed significant positive relationship between SOC and GWC (Table 4).

Table 4: Significant correlations among different yield at first harvest, soil physical, chemical and biological properties and status of decomposition of crop residues (weight loss percentage) in a banana cultivated soil.

Correlations[1]	**Pearson coefficient (R^2)**	**Significance (*P*-value)**
Yield and CC	0.477*	0.045
Yield and Bacteria abundance	0.536*	0.022
CC and GWC	0.686**	0.002
SOC and GWC	0.522*	0.026
GWC and VWC	0.661**	0.003
Bacteria and Cellulose decomposers abundance	0.535*	0.032
Fungi and SWLT1D2	0.497*	0.036
BD and GWC	-0.552*	0.018
GWC and SWLT1D1	-0.612**	0.007
Cellulose decomposers and LWLT2D1	-0.503*	0.033
VWC and Bacteria abundance	- 0.509*	0.031
VWC and SWLT1D1	-0.505*	0.032
BD and Bacteria abundance	- 0.564*	0.015
BD and Cellulose decomposers abundance	- 0.592**	0.010
BD and CC	- 0.505*	0.032

[1] CC – clay content; SOC – Soil organic carbon; GWC - Gravimetric water content; VWC – Volumetric water content; BD – Bulk density; SWLT1D2 – Stem weight loss at 17 DAP at 7.5cm depth; SWLT3D2 – Stem weight loss at 45 DAP at 7.5cm depth; SWLT1D1 – Stem weight loss at 17 DAP on surface; LWLT2D1 – Leaves weight loss at 31 DAP on surface

* Significant at *P*=0.05

** Significant at *P*=0.01

According to Rawls et al. [45], water retention ability depends on the initial amount of SOC and the textural components of a given soil. In the experimental plots of the banana plantation of the present study, crop residues after every harvest are added to soil as a surface mulch. Therefore, the initial amount of SOC content could be assumed as same for every treatment. Interestingly, the application of PM has not changed the SOC significantly. Manns et al. [46] reported that clayey soils, which contain more micro pores compared to macro pores, can hold more water, increasing the GWC of those soils. That may emphasize the reason for the positive correlation between CC and GWC (Table 4). Perdok et al. [47], explained that at a given BD, VWC is increased with the increase of GWC. Thus, GWC and VWC could have positive correlation as seen in the present study (Table 4). Although these physical properties were not significantly affected by the nutrient management treatments, the observed significant correlations suggest high spatial variability and spatial structuring of the measured properties in the experimental site.

Soil BD is the governing factor for the infiltration, available water content, soil porosity, rooting depth, activity of soil microorganisms and nutrient availability in soil [48]. Therefore, higher BD lowers the abundance of soil organisms as also seen in the present study (Table 4). Soil bulk density is influenced by the soil texture. Tanveera et al. [49] observed a negative correlation between bulk density and clay content in the soil. Clay could support to build up a good soil structure lowering BD. The populations of soil fungi, cellulose decomposers and soil moisture status significantly influenced the decomposition of crop residues (Table 4).

In the present study, inclusion of PM application together with CF as an integrated nutrient management program has resulted in positive impact on land productivity and soil fertility. Although the last PM application event was nearly one year before analyzing the decomposers' activity and soil properties, profound effects of the history of PM application could be seen on soil BD and biological properties important for decomposition of crop residues. Bulk density had strong correlations with biological activities and water availability in soil. Considering that the farm is located in a relatively dry area of the country and already facing challenges in proper management of soil moisture during dry spells as well as in rainy seasons, it is advantageous to take measures to improve soil BD. Therefore, continuing the application of PM as part of the crop nutrient management program in this banana plantation could improve soil fertility, supporting sustainable crop production.

4. CONCLUSION

The yield of Cavendish banana under 100% and 75% of site specific CF application was not significantly different. Therefore, the CF usage in the farm can be reduced up to 75%. Inclusion of PM application together with CF resulted in increase in crop yield, and affected soil biological properties and soil bulk density positively. Hence, it is recommended to include PM together with CF as integrated nutrient management practice for banana cultivation in the studied farm. The PM can be applied at 2.5 kg/plant application rate at least to have a positive impact on soil fertility and crop productivity than applying CF alone. The rate of decomposition of crop residues in the banana cultivated field was largely determined by the type of crop residue and the time of exposure to decomposition in soil rather than the nutrient management practices or the depth of crop residue incorporation to soil. Although the results indicated that nutrient management practices, i.e. using CF alone or together with PM did not have an impact on decomposition of crop residues during the study period, the significant changes observed in soil biological and physical properties, and the observed correlations among soil properties indicate that PM application had a positive impact on soil fertility conditions. Therefore, continuation of application of PM to soil could result in changes in crop residue decomposition, which require further investigations.

COMPETING INTERESTS DISCLAIMER:

Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

Disclaimer (Artificial intelligence)

Authors hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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