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Effects of Poultry Manure Biogas Residues and Conventional Fertilizers on Growth and Yield of Tomato (*Lycopersicon esculentum* (L.) Mill.)

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Abstract
Tomato (*Lycopersicon esculentum* (L.) Mill.) production relies heavily on nutrient availability, which significantly influences plant growth, yield, and fruit quality. With rising demand for sustainable agriculture, poultry manure biogas residues (PMBR) are gaining attention as alternatives or supplements to synthetic fertilizers. This study assessed the effects of PMBR compared to conventional fertilizers (NPK) under field conditions using a randomized complete block design with six treatments: sole PMBR (20 ton ha^{-1}), sole NPK (100% RDF: 135 kg N ha^{-1}, 45 kg P ha^{-1}, 75 kg K ha^{-1}), and combined PMBR–NPK applications (15 ton ha^{-1} PMBR + 25% RDF, 10 ton ha^{-1} PMBR + 50% RDF, 5 ton ha^{-1} PMBR + 75% RDF). Growth parameters (leaves, height, branches) and yield parameters (fruit number, weight, total yield) were measured. Results showed integrated PMBR–NPK treatments achieved the highest yields, while sole PMBR maintained comparable performance with reduced inputs, highlighting PMBR's potential as an eco-friendly, cost-effective nutrient source.

***Keywords*:** Poultry manure, nutrient management, soil fertility, plant growth and manure rate.

Introduction

Tomato (*Lycopersicon esculentum* (L.) Mill.) is one of the most widely cultivated horticultural crops worldwide, valued not only for its economic importance but also for its nutritional profile, which includes vitamins, minerals, antioxidants, and other bioactive compounds beneficial to human health[1,2]. Global tomato production has steadily increased over recent decades, yet meeting the growing demand requires sustainable agricultural practices that enhance yield without degrading the environment[3]. Conventional production systems often rely heavily on synthetic fertilizers to meet nutrient requirements, but their prolonged use can lead to soil degradation, reduced biodiversity, nutrient imbalances, and increased greenhouse gas emissions[4]. In light of these challenges, the search for alternative, eco-friendly nutrient sources have become a pressing global priority in sustainable agriculture[5].

In response to these environmental and agronomic concerns, there has been a paradigm shift toward sustainable nutrient management strategies that minimize ecological harm while maintaining crop productivity. Organic amendments, particularly those derived from agricultural waste streams, have emerged as promising alternatives or complements to mineral fertilizers. Poultry manure is a notable that is a nutrient-rich organic material containing substantial amounts of nitrogen, phosphorus, potassium, and micronutrients in forms that can benefit plant growth[6,7]. However, direct application of fresh poultry manure can result in issues such as nutrient leaching, greenhouse gas emissions, odor, and pathogen risks[8]. The anaerobic digestion of poultry manure to produce biogas not only provides renewable energy but also yields a stabilized byproduct known as biogas residue or digestate. This residue retains a significant proportion of the manure original nutrients, often in more plant-available forms, while reducing the microbial load and odor[9,10]. Consequently, poultry manure biogas residue offers the dual benefits of waste valorization and soil fertility enhancement.

Around 80,000 biogas plants are already in operation in Bangladesh; most of which are small domestic systems based on cow dung and poultry litter and are used for cooking. Several large poultry farms have already completed construction of larger commercial biogas plants (more than 350 m^3/day capacity with single digesters[11]. Over 25,000 dairy and 1,50,000 poultry farms in the country could benefit from the technology by reducing the use of traditional cooking fuels and diesel for power generation (the cost of construction is usually earned back in two to three years), as well as preventing diseases and producing pathogen- free organic fertilizer[11].

Despite growing recognition of biogas residue as a potential biofertilizer, much of the current research has focused on residues derived from cattle or pig manure[12]. Studies specifically examining poultry manure biogas residue are comparatively limited, particularly in relation to high-value vegetable crops such as tomato. Furthermore, existing studies often concentrate on soil chemical properties rather than plant physiological responses, yield performance, or quality attributes. There is also a lack of field-based evidence under varying environmental conditions to confirm the agronomic efficiency of poultry manure biogas residue relative to conventional fertilizers. Tomato is selected for this study due to its global agronomic and nutritional significance, being one of the most widely consumed vegetables. Rich in vitamins, minerals, and bioactive compounds such as lycopene and β-carotene, tomato contributes to human health while also serving as a sensitive model for evaluating the biochemical impacts of environmental stressors[13,14].

The present study was designed to address these gaps by investigating the effect of poultry manure biogas residue on the growth, yield, and related agronomic traits of tomato under field conditions. Specifically, the research aimed:
(1) to evaluate the influence of different application rates of poultry manure biogas residue on vegetative growth parameters such as number of leaves, plant height and number of branches; (2) to assess its impact on yield components including fruit number, fruit weight, and total yield.

Materials and Methods

Experimental Site and Location

The experimental site was located at 22°47′ N latitude, 91°78′ E longitude, and 30 m above mean sea level[15]. Chattogram's climate is tropical monsoon, with a pronounced rainy season from June to September and a dry, rainless winter from mid-December to mid-February. The annual mean temperature is 25.9°C, peaking in May at 28.5°C and dipping in January to 19.9°C. Recorded extremes range from 36.1°C in August to 11.1°C in November[16]. Average annual rainfall is 2918.5 mm, with July receiving the highest monthly average of 726.4 mm and January the lowest at 5.1 mm. Mean annual relative humidity is 73.7%, ranging from 58% in January–February to 86% in August. According to the Holdridge life zone classification, Chattogram falls within the tropical moist forest biome.

Soil Sampling and Preparation

Composite surface soil samples from a depth of 0-15cm were collected from experimental field before preparing the land for cropping by using auger for analysis of selected physical and chemical properties including texture, pH, organic matter, total nitrogen, available phosphorus etc. In the same way, soil samples were collected from each plot just after harvest to determine the post-harvest properties of soil. Soil samples were air dried and ground to pass through 2.0 mm sieve and these sieved soil samples were stored in the plastic pots for laboratory analysis. The physical and chemical properties of soil were determined according to standard methods at the laboratory of Department of Soil Science, University of Chittagong. The physical and chemical properties of experimental site soil (dry weight basis) are presented in Table 1.

Table1. Physical and chemical properties of soil.

Properties	Value
Sand (%)	52.42
Silt (%)	31.67
Clay (%)	15.92
Texture	Sandy loam
Organic carbon (%)	0.23
pH	4.85
EC (μs cm^{-1})	35.2
Total N (%)	0.1
Available P (mg kg^{-1})	10
Total P (%)	0.05
Total K (%)	0.43
Total Ca (%)	0.27
Total Mg (%)	0.07
Total Na (%)	0.18
Total Fe (%)	0.410
Total Zn (%)	0.021

Collection of Poultry manure biogas residues (PMBR)

Poultry manure biogas residues (PMBR) were collected from 'Masud Krishi Complex' located at Patiya, Chattogram. After collection, PMBR was air dried and stored for application. A portion of the air dried PMBR was sieved through 2.0mm sieve and was preserved in plastic pots for analysis in the laboratory. The properties of biogas residues determined by following same methods of soil analyses (dry weight basis) are given in Table 2.

Table 2. Properties of poultry manure biogas residues

Properties	Value
pH	7.13
EC (µs cm^{-1})	828
Organic carbon (%)	10.08
Total N (%)	1.22
Total P (%)	3.09
Total K (%)	0.08
Total Ca (%)	4.13
Total Mg (%)	0.29
Total Na (%)	0.45
Total Fe (%)	0.32
Total Zn (%)	0.12

Treatment, Experimental design and Layout

There were six treatments comprising of poultry manure biogas residue (PMBR) and conventional (NPK) fertilizers. The treatments are described in Table 3. The experiment was laid out in randomized complete block design (RCBD) with three replications of each treatment.

Table 3. Treatments used in the field experiment

Treatment	Treatment contains
T_1	Control (No PMBR+ No NPK fertilizer)
T_2	100% RDF@ 135kg N ha^{-1}, 45 kg P ha^{-1} and 75 kg K ha^{-1}
T_3	20 ton ha^{-1} Poultry manure biogas residues (PMBR)
T_4	15 ton ha^{-1} PMBR + 25% RDF
T_5	10 ton ha^{-1} PMBR + 50% RDF
T_6	5 ton ha^{-1} PMBR + 75% RDF

Where, 100% RDF= Recommended dose of NPK fertilizer (135kg N ha^{-1}+45kg P ha^{-1}+75kg K ha^{-1}) for tomato[17]

25% RDF = 33.75 kg N ha^{-1}+ 11.25 kg P ha^{-1}+ 18.75 kg K ha^{-1}

50% RDF = 67.5 kg N ha^{-1}+ 22.5 kg P ha^{-1} + 37.5 kg K ha^{-1}

75% RDF = 101.25 kg N ha^{-1}+ 33.75 kg P ha^{-1} + 56.25 kg K ha^{-1}

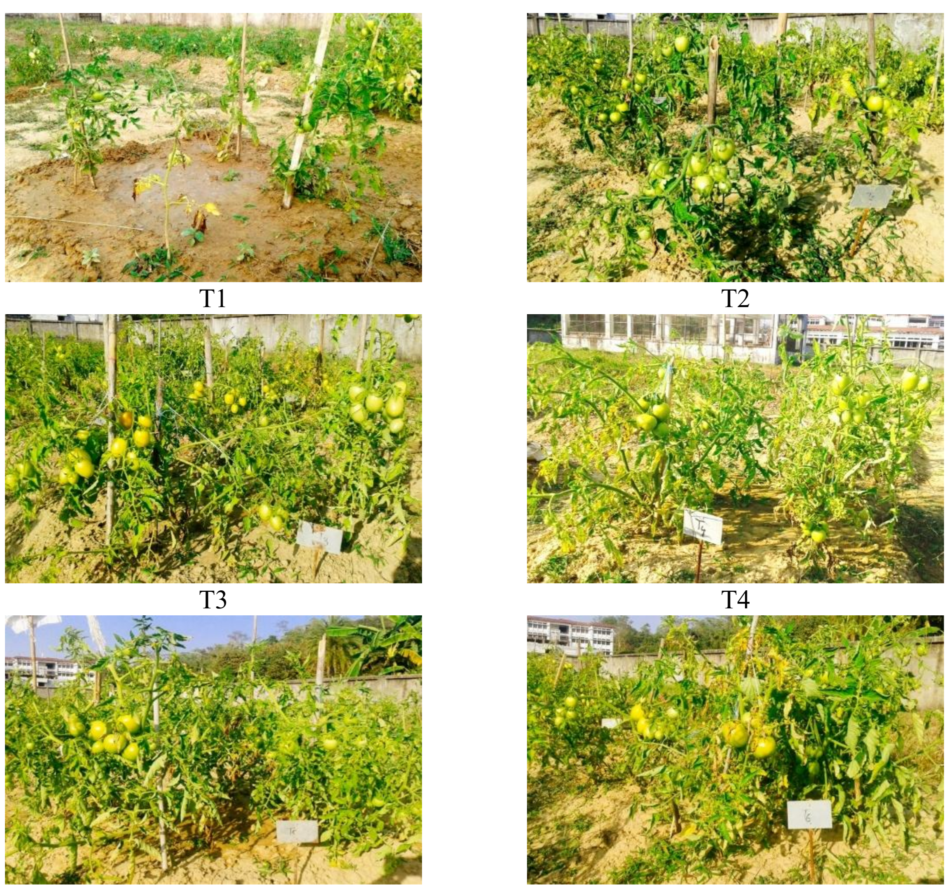

Figure 1. Effects of different treatments on tomato.

Preparation of Experimental Plot

The land was ploughed deeply and leveled properly. Each unit plot was 1m × 1m ($1m^2$) in size and separated by 0.5 m wide furrows. Furrows were made manually in such a way that it allows proper draining of excess water from plots. The PMBR doses for each treatment were mixed with soil properly and allowed to equilibrate for 20 days.

Nitrogen and potassium fertilizers in the form of urea and MP were applied in two equal splits. These splits were applied at 15 and 35 days after transplantation respectively as basal. All of the phosphorus in the form of TSP was applied at the first split during final land preparation.

Tomato seeds (BARI-14) were collected from Regional Agriculture Development Centre, Hathazari, Chattogram, Bangladesh. Seeds were sown in a seedbed of 3m×5m area. Four healthy seedlings of 30 days old with almost the same stem length were transplanted in four corners of each unit plot maintaining 75 cm spacing between seedling to seedling.

Cultural practices such as weeding, hoeing, watering, staking, disease and pest control were applied uniformly for all treatments. During the course of the study, fungicide was applied two times at two-week interval to control leaf blight and late blight since the incidence was observed.

Growth and Yield Components

The number of leaves plant^{-1}, plant height and number of branches plant^{-1} were recorded at 30, 45 and 60 days after transplantation of seedlings to assess the plant growth. The fruits were harvested at 4 to 5 days interval when matured and ripened. The number of fruits plant^{-1}, weight of fruits plant^{-1} and yield were recorded during harvest. Percent yield increase was calculated to compare the effects of treatments on tomato fruit yield by following the formula[18],

$$\%\ \text{Yield increase} = \frac{\text{Yield}_{\text{treatment}} - \text{Yield}_{\text{control}}}{\text{Yield}_{\text{control}}} \times 100$$

Analysis of Soil

The soil samples were analyzed for some parameters relevant to the study at the laboratory. The particle size distribution and textural class of the soil were determined by hydrometer method of Day[19]. Soil pH was determined by glass electrode pH meter (Mettler Toledo Seven Compact pH Meter) with a soil water ratio of 1: 2.5[20]. Electrical conductivity (EC) was measured by Ec 214 Conductivity Meter. Organic carbon content of soil was determined by wet combustion with $K_2Cr_2O_7$[21]. Organic matter content was determined by multiplying the organic carbon content with 1.724. Total nitrogen was determined according to Micro-Kjeldahl method with H_2SO_4 as described by Bremner[22]. Determination of available phosphorus was carried out with the extraction method of Bray and Kurtz[23]. Soil samples were digested by H_2SO_4 with a mixture of Na_2SO_4, $CuSO_4$ and Se powder for the determination total K, Na, Ca, Mg, Fe, Zn[24]. The concentrations of K, Na Ca, Mg, Fe and Zn in digest were measured by Atomic Absorption Spectrophotometer (Agilent Technologies 240AA).

Data Analysis

The significance of differences among means of the treatments was evaluated by one-way analysis of variance (ANOVA) followed by Duncan's Multiple Range Test (DMRT) at the significance level of 5%. The statistical software Microsoft Excel[25] and SPSS version 20 were used for analysis.

Results and Discussion

Growth Parameters

The number of leaves plant^{-1} of tomato was recorded at 30, 45 and 60 days after transplantation of seedlings. Mean values of number of leaves plant^{-1} are shown in Figure 2. Number of leaves was the minimum at the control in all the periods of recording 30 DAT, 45 DAT and 60 DAT. The corresponding values were 65.17, 123.83 and 147.50. Addition of 100% RDF (treatment T2) did not significantly increase the number of leaves plant^{-1}. Addition of poultry manure biogas residues (PMBR) alone or in combination with inorganic fertilizers increased significantly the number of leaves plant^{-1} at all the periods. Application of 20 t ha^{-1} PMBR (treatment T3) alone increased the number of leaves plant^{-1} to 226, 496 and 647 at the respective periods. The highest number of leaves plant^{-1} at 30 DAT (226) was obtained with treatment T3 (Poultry manure biogas residues @ 20t ha^{-1}) whereas the highest number of leaves plant^{-1} at 45 DAT (526.67) and 60 DAT (807.67) was obtained in treatment T5 (10t ha^{-1} PMBR+ 50% RDF). Values of number of leaves plant^{-1} at 30 DAT in treatments T4, T5 and T6 did not differ significantly. Similar results were found among the treatment T3, T4 and T6 at 60 DAT.

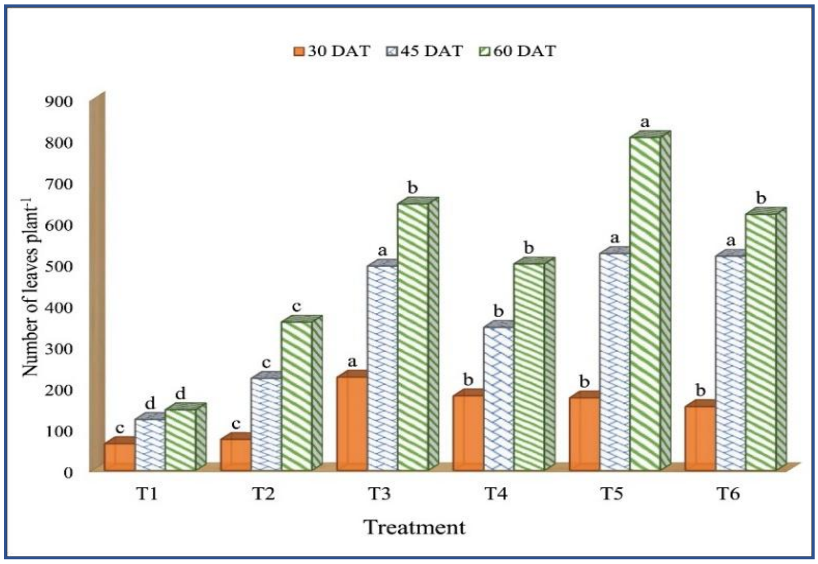

Figure 2. Effects of different treatments on the number of leaves plant^{-1} of tomato. Bars having same letter(s) are not significantly different among treatments by DMRT (p≤ 0.05).

Plant height is one of the most important characteristics of tomato plant. The plant height of tomato was measured after 30, 45 and 60 days after transplantation (DAT) of tomato seedlings and the results are presented in the (Figure 3). Height of plants varied from 25.33 (control) to 46.08 cm (T3) at 30 DAT, 41.83 (control) to 76.67 cm (T5) at 45 DAT, and 46.50 (control) to 85.17 cm (T5). Thus, the minimum value was always obtained in the control and the maximum values were obtained with the poultry manure biogas residues alone @ 20t ha^{-1} at 30 DAT and with 10t ha^{-1} PMBR+ 50 % RDF at 45 and 60 DAT. Inorganic fertilizer and poultry manure biogas residues increased height of plants but at different rates with kind and combination. In PMBR @20t ha^{-1} (T3) the values were 46.08 cm at 30 DAT, 75.33cm at 45 DAT, and 80.00 cm at 60 DAT. The treatment of 100% RDF (T2) produced 27.92 cm at 30 DAT, 52.00 cm at 45 DAT and 68.33 cm at 60 DAT. Plant heights in 100% RDF (T2) was significantly lower than that in poultry manure biogas residues alone or in combination with inorganic fertilizer (T3, T4, T5 and T6) at 30 and 45 DAT but was higher than control at all the periods. Values of plant height at 30 and 60 DAT in treatments T3, T4, T5 and T6 did not differ significantly.

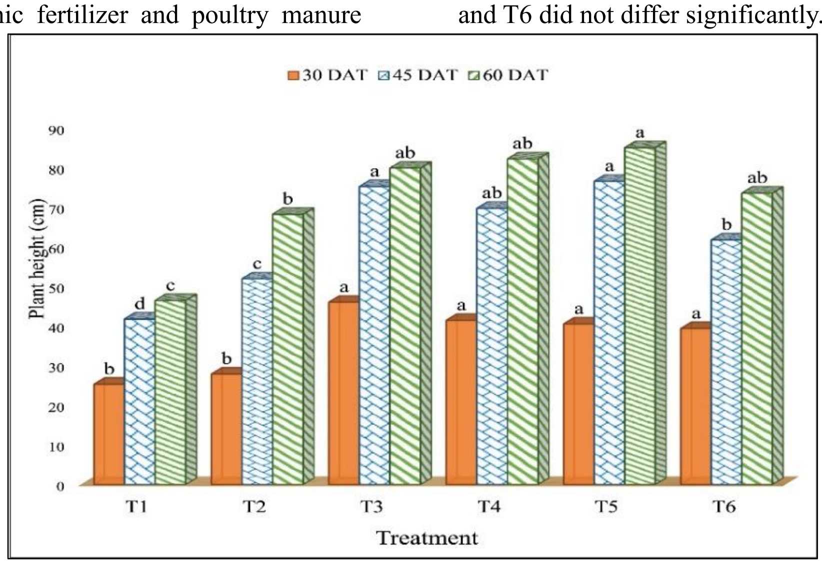

Figure 3. Effects of different treatments on plant height of tomato. Bars having same letter(s) are not significantly different among treatments by DMRT (p≤ 0.05).

Number of branches plant^{-1}, is shown in Figure 4. The highest value of number of branches plant^{-1} was found in treatment T3 (8.92; PMBR @ 20 t ha-1) at 30 DAT, in treatment T6 (11.00; 5 t ha $^{-1}$ PMBR + 75% RDF) at 45 DAT and in treatment T5 (15.33; 10 t ha $^{-1}$ PMBR + 50% RDF) at 60 DAT. Number of branches plant^{-1} was the lowest in treatment T1 (control) at all the periods of recording 30 DAT, 45 DAT and 60 DAT. The corresponding values were 1.67, 1.67 and 3.33, respectively. Poultry manure biogas residues alone or in combination with inorganic fertilizer (T3, T4, T5 and T6) significantly increased the number of branches plant^{-1} at 30, 45 and 60 DAT. However, the values of number of branches plant^{-1} in treatments T3, T4, T5 and T6 did not differ significantly. In other words, all the PMBR treatments increased the number of branches plant $^{-1}$ to the same extent. It also indicated that poultry manure biogas residues alone or its different combinations with inorganic fertilizer had similar effects on number of branches plant^{-1}.

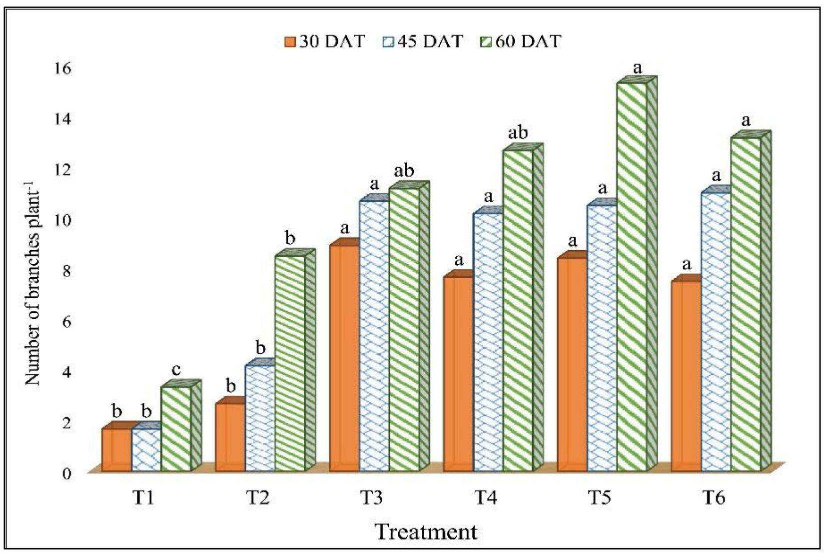

Figure 4. Effects of different treatments on number of branches plant^{-1} of tomato.
Bars having same letter(s) are not significantlydifferent among treatments by DMRT (p≤ 0.05).

Yield Parameters

Number of fruits plant^{-1} is the most important yield attributing character of tomato plant. The value of total number of fruits plant^{-1} ranged from 5.08 to 27.67 (Table 4). The highest number of fruits plant^{-1} was observed in treatment T4 where poultry manure biogas residues @ 15 t ha^{-1} mixed with 25% RDF was applied. The lowest number of fruits plant^{-1} was observed in control treatment T1 where no fertilizer and biogas residues were applied. Application of 100% RDF did not significantly increase the number of fruits plant^{-1} from that of the control. Addition of poultry manure biogas residues (PMBR) alone or in combination with inorganic fertilizers in treatment T3 (20t ha^{-1} PMBR), T4 (15t ha^{-1} PMBR+25% RDF), T5 (10t ha^{-1} PMBR+50% RDF) and T6 (5t ha^{-1} PMBR+75% RDF) increased significantly the number of fruits plant^{-1} compared to control treatment T1. However, the number of fruits plant^{-1} obtained in the treatments T3, T4, T5 and T6 were not significantly different from each other.

Table 4 Number of fruits, fruit weight and yield of tomato as affected by different treatments.

Treatment	No of fruit Plant^{-1}	Single fruit weight(g)	Weight of fruits (kg plot^{-1})	Yield (ton/ha)	% Yield increase
T1	5.08 c	38.28 c	0.77 d	7.68 e	0.00 e
T2	10.58 c	52.70 ab	2.08 c	20.82 d	162.41 d
T3	24.58 ab	40.10 bc	3.95 b	39.52 c	414.62 c
T4	27.67 a	41.80 bc	4.58 b	45.86 bc	497.18 bc
T5	25.83 ab	56.59 a	5.82 a	58.22 a	658.12 a
T6	20.83 b	59.94 a	4.99 ab	49.96 ab	550.56 ab

Mean values within a column followed by same letter(s) are not significantly different by DMRT ($P \leq 0.05$).

The single fruit weight of tomato in this study ranged from 38.28 g to 59.94 g (Table 4). The highest single fruit weight was found in treatment T6 (5 t ha^{-1} PMBR + 75% RDF) and the lowest single fruit weight was found in treatment T1 (control). A significant variation in single fruit weight of tomato was observed among the treatments. However, single fruit weight found in treatment T3 and T4 did not differ significantly from that in treatment T1 (control). Single fruit weight of tomato found with 100% RDF (T2) was significantly higher than that of the control (T1) but was statistically similar to that with the treatment T3, T4, T5 and T6.

Weight of fruits plot^{-1} under different treatments in the present study varied from 0.77 kg in treatment T1 (control) to 5.82 kg in treatment T5 where poultry manure biogas residues @10 t ha^{-1}mixed with 50% RDF was applied (Table 4). Addition of inorganic fertilizer and poultry manure biogas residues individually and their different combination significantly increased weight of fruits plot^{-1} from that with the control (T1). Weight of fruits plot^{-1} obtained with 100% RDF (T2) was significantly higher than that with control (T1) but lower than that with poultry manure biogas residues applied individually (T3) and its different combination with inorganic fertilizer in treatment T4, T5 and T6. However, there were no significantly differences in weight of fruits plot^{-1}among treatments T3, T4 and T6 and between T5 and T6.

Yield is the most important characteristics for the justification of evaluation of tomato genotypes and varieties. It was observed that yield of tomato varied from 7.68 t ha^{-1} to 58.22 t ha^{-1} among the treatments (Table 4). The highest yield was obtained in applying poultry manure biogas residues @ 10t ha^{-1} mixed with 50% RDF (T5) and the lowest yield was obtained in control treatment T1 where no fertilizer or PMBR was applied. Addition of inorganic fertilizer and poultry manure biogas residues in different treatments significantly increased yield of tomato compared to the control (No fertilizer and PMBR). This may be due to very low fertility of the experimental soils. Yield of tomato obtained in treatment T2 (20.82 t ha^{-1}; 100% RDF) was significantly higher than that in the treatment T1 (7.68t ha^{-1}; control) but lower than that in T3 (39.52 t ha^{-1}; PMBR @ 20t ha^{-1}), T4 (45.86t ha^{-1}; 15t ha^{-1} PMBR+ 25% RDF), T5 (58.22 t ha^{-1}; 10 t ha^{-1} PMBR+ 50% RDF), and T6 (49.96t ha^{-1}; 5t ha^{-1} PMBR+ 75% RDF). However, yield of tomato was not significantly different in between T3 and T4 treatments. Similar result was found in between T5 and T6 treatments. The yield of tomato in treatment T5 was significantly higher than that of treatment T3 and T4.

Yield increase of tomato by application of inorganic fertilizers and poultry manure biogas residues over control was in the range from 162.41% in treatment T2 (100% RDF) to 658.12% in treatment T5 (10t ha^{-1} PMBR+ 50% RDF) (Table 4). A significant increase of yield by PMBR and conventional fertilizers treatments over control might be due to very poor fertility of the experimental soil. The treatment T2 (162.41 %; 100% RDF) significantly differed from the control treatment. Yield increased in treatment T3 (414.62%; 20t ha^{-1} PMBR) and T4 (497.18%; 15t ha^{-1} PMBR+25 % RDF) were statistically similar with each other but were significantly higher than that in the treatment T2 and lower than that in the treatment T5 (658.12%; 10t ha^{-1} PMBR+50 % RDF) and T6 (550.56%; 5t ha^{-1} PMBR+75 % RDF) over control. Yield increased in treatment T5 and T6 did not differ significantly from each other.

The growth characteristics (in terms of number of leaves plant^{-1}, number of branches plant^{-1} and plant height, number of fruits, single fruit weight) as well as yield of tomato were significantly affected by treatments of conventional fertilizer, poultry manure biogas residues and their different combination except number of leaves plant^{-1} at 30 DAT and number of fruits plant^{-1} by 100% recommended doses of fertilizer (RDF). While plant height and number of branches consistently increased until T5, there was a sudden decrease in the number of leaves at T4 that might be due to the deviation from optimal ranges for some environmental factors like light intensity, water availability and temperature that are critical for determining a plant's number of leaves as they influence essential processes like photosynthesis and cell differentiation. In accordance with the present study, Islam et al.[26] reported that application of solid waste slurry from biogas plant resulted in increase of plant height of spinach. Although the number of fruits plant^{-1} of tomato in treatment T5 (10t ha^{-1} PMBR+ 50% RDF) was statistically similar to that in T3 (20t ha^{-1} PMBR) and T4 (15t ha^{-1} PMBR+ 25% RDF) but the yield of tomato in treatment T5 was significantly higher than that in the treatments T3 and T4. This may be due to significantly higher single fruit weight of tomato in treatment T5 compared to treatment T3 and T4. Poultry manure biogas residues alone and its different combination with inorganic fertilizer gave higher number of leaves plant^{-1}, plant height, number of fruits plant^{-1} and fresh fruit yield than 100% RDF alone. Application of 10 t ha^{-1} poultry manure biogas residues+ 50% recommended dose fertilizer proved most effective in ensuring good performance in terms of growth and fresh fruit yield of tomato in valley soils of Chittagong, Bangladesh. Addition of 10t ha^{-1} PMBR+50% RDF increased tomato yield by 658.12% over control. In agreement with the present study, Grameen Shakti[27] reported that application of 50% recommended dose inorganic fertilizer +2t ha^{-1} cow dung biogas residues increased the yield of cabbage, brinjal and tomato by 480, 336 and 284% respectively compared to control. The yield responses were comparable with those of 100% recommended fertilizer doses. Bangladesh Agricultural Research Institute[28] recorded about 371% yield increase of cabbage over native fertility by 5t ha^{-1} cow dung slurry with integrated plant nutrient system (IPNS) base inorganic fertilizer. Yield increase due to application of 3t ha^{-1} poultry manure slurry with IPNS base inorganic fertilizer was 394%[28]. Manna and Hazra[29] also reported an increase of cob yield of maize by application of biogas slurry. Qi et al.[30] examined the effect of fermented waste as organic manure in cucumber and tomato production in North China. Before the vegetables transplantation, the diluted fermented residual dreg was applied 20-30 cm below the soil surface at a rate of 37,500 kg ha^{-1}, while liquid digestate was sprinkled to the soil surface in three vegetables growing stages and on the vegetable leaves once time. They found increasing yield (18.4% and 17.8%) and vitamin C content (16.6% and 21.5%) of treated cucumber and tomato, respectively.

The low C/N ratio in biogas residue, compared to untreated manure, leads to decreased N immobilization, and consequently, reduced N mineralization and bioavailability at the time of application[31, 32, 33, 34]. In general, biogas residue presents an efficient nitrogen source for plants with the potential to improve crop yield and soil properties[35, 36, 37, 38]. However, it is important to remember that N is the most common limiting factor for crop growth in organic farming systems [39, 40, 41, 42] owing to failure in synchronizing crop N demand and supply to the soil by mineralization of organic fertilizers[43].

The issue of how effectively biogas residue can substitute common artificially produced mineral fertilizers in terms of crop yield is of significant interest. A recent report by Montemurro *et al*.[44] focused on determining the potential of biogas residue in crop yield. During a two-year field experiment, no significant differences were observed in the cumulative plant dry weight of alfalfa subjected to different fertilizer treatments (anaerobic digestates and mineral fertilizers), whereas for cocksfoot crops, mean yield was higher in plots treated with biogas residue in relation to control plots. At the end of the trial, no heavy metals were detected in either plants or soil, and plant nutrient content was not affected by fertilizer application. It is concluded that biogas residue could be effectively utilized in the short term to provide nutrients to crops[44]. In another study, Kocar[45] compared the fertilizer value of anaerobically digested cattle slurry with those of commercial organic and chemical fertilizers. Higher yields of safflower were obtained with biogas residue than commercial organic and chemical fertilizers. It is suggested that the input of chemical fertilizers should decrease with the use of anaerobically digested residues, whereas soil texture is improved[45]. Chantigny *et al*.[46] reported similar fertilizer values of raw and anaerobically treated liquid swine manure to that of mineral fertilizer upon immediate incorporation into soil[46], supporting the significant potential of biogas residue as a valuable substitute and/or complement to mineral fertilizers.

A study by Rivard *et al*.[47] showed that dried and composted biogas residue produced from municipal solid waste induced an increase in crop weight (i.e., corn) and plant yield in direct proportion to the residue application rate. Marchain[48] disclosed that biogas residue induced a 6-20% higher yield in vegetable production, clearly signifying that a broad range of plants potentially benefit from this mode of fertilization, including vegetables and cereals. However, since biogas residue contains a significant proportion of mineralized N, crops that display a short and intensive period of N uptake should preferably be fertilized using this method[49, 50] to minimize N leakage. Odlare *et al*.[51] concluded that biogas residue may contain higher amounts of mineral N and easily degradable C (for instance, compared to compost)[52], and should hence be more efficient in supplying available N to crops than other types of organic waste[51]. In contrast, El-Shakweer *et al*. [53] reported similar crop yields using soil amended with air-dried biogas residue and unmodified soil, and other studies report that anaerobic digestion results in relative enrichment of heavily degradable compounds[54, 55]. Nevertheless, biogas residue is evidently an efficient N source for the fertilization of agricultural crops[49]. Notably, soil fertilized with biogas residue requires phosphorus (i.e. superphosphate) supplementation to avoid P deficits[49], emphasizing the need to analyze and monitor the quality of biogas residue before indiscriminate application to agricultural land as a fertilizer.

Conclusion

The results showed that applying PMBR, whether on its own or together with NPK, led to markedly better vegetative growth and higher yields than using conventional fertilizers alone. A total of six treatments were evaluated, with their effectiveness in promoting growth and yield ranked as follows: T5 (10t ha^{-1} PMBR + 50% RDF) > T6 (5t ha^{-1} PMBR + 75% RDF) > T4 (15t ha^{-1} PMBR + 25% RDF) > T3 (20t ha^{-1} PMBR) > T2 (100% RDF) > T1 (control). PMBR demonstrated soil chemical improvements, plant growth, and fruit yields comparable to or exceeding those of conventional fertilizers, highlighting its potential as a cost-effective alternative. However, its widespread adoption depends on farmer acceptance, which can be strengthened through long-term field trials that confirm agronomic benefits. Future research should be clarifying how feedstock composition influences soil-amending properties, assess its long-term impacts on soil chemistry and structure, establish pathogen monitoring protocols, and quantify greenhouse gas emission factors to optimize PMBR use for sustainable agriculture.

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References

1. Hossain, E., Ahamed, K. U., Shamsuzzaman, A. M. M., Haque, M., and Nahar, K. 2017. Yield and morph-physiological performance of different tomato varieties in winter season. *Middle-East Journal of Scientific Research*, **25(6)**,1216-1224. https://doi.org/10.5829/idosi.mejsr.2017.1216.1224
2. Gierson, D., and Kader, A. A. 1986. Fruit ripening and quality. In *The tomato crop: A scientific basis for improvement* (pp. 241-280). Dordrecht: Springer Netherlands.
3. Gatahi, D. M. 2020. Challenges and opportunities in tomato production chain and sustainable standards. *International Journal of Horticultural Science and Technology*, **7(3)**, 235-262. https://doi.org/10.22059/ijhst.2020.300818.361
4. Wan, L., Liu, G., and Su, X. 2025. Organic fertilization balances biodiversity maintenance, grass production, soil storage, nutrient cycling and greenhouse gas emissions for sustainable grassland development in China: A meta-analysis. *Agriculture, Ecosystems & Environment*, **381**, 109473. https://doi.org/10.1016/j.agee.2025.109473
5. Katiyar, R. B., Sundaramurthy, S., Sharma, A. K., Arisutha, S., Pratap-Singh, A., Mishra, S., Ayub, R., Jeon, B.-H., and Khan, M. A. 2023. Vermicompost: An Eco-Friendly and Cost-Effective Alternative for Sustainable Agriculture. *Sustainability*, **15(20)**,14701. https://doi.org/10.3390/su152014701
6. Agyarko-Mintah, E., Cowie, A., Singh, B. P., Joseph, S., Van Zwieten, L., Cowie, A., Harden S., and Smillie, R. 2017. Biochar increases nitrogen retention and lowers greenhouse gas emissions when added to composting poultry litter. *Waste Management*, **61**,138-149. https://doi.org/10.1016/j.wasman.2016.11.027

7. Garg, R. N., Pathak, H., Das, D. K., and Tomar, R. K. 2005. Use of flyash and biogas slurry for improving wheat yield and physical properties of soil. *Environmental monitoring and assessment*, **107(1)**, 1-9.
8. Novais, S.V., Zenero, M.D.O., Frade Junior, E.F., de Lima, R.P. and Cerri, C.E.P. 2017 Mitiga tion of Greenhouse Gas Emissions from Tropical Soils Amended with Poultry Manure and Sugar Cane Straw Biochars. *Agricultural Sciences*, **8**, 887-903. https://doi.org/10.4236/as.2017.89065
9. Mozhiarasi, V., and Natarajan, T. S. 2025. Slaughterhouse and poultry wastes: management practices, feedstocks for renewable energy production, and recovery of value added products. *Biomass conversion and biorefinery*, **15(2)**, 1705-1728. https://doi.org/10.1007/s13399-022-02352-0
10. Möller, K., Schulz, R., and Müller, T. 2009. *Mit Gärresten richtig Düngen: aktuelle Informationen für Berater*. Univ. Hohenheim.
11. Ahmed Z. and Talukder M.F.S.I. 2016. Meeting Energy Needs with Biogas Technology. GIZ, Dhaka-1212, Bangladesh.
12. Tambone, F., Scaglia, B., D'Imporzano, G., Schievano, A., Orzi, V., Salati, S., and Adani, F. 2010. Assessing amendment and fertilizing properties of digestates from anaerobic digestion through a comparative study with digested sludge and compost. *Chemosphere*, **81(5)**,577-583. https://doi.org/10.1016/j.chemosphere.2010.08.034
13. Alajmi, R., Al-Shammari, M., Abdel-Gaber, R., Metwally, D., El-Khadragy, M. F., and Alrajeh, A. 2021. Effectiveness of naturally occurring Aphis gossypii on tomato plants as a bio-indicator for heavy metals in Riyadh and Hafar Al-Batin, Saudi Arabia. *Saudi Journal of Biological Sciences*, **28(7)**, 4096-4101. https://doi.org/10.1016/j.sjbs.2021.04.027
14. Seyfferth, A. L., Limmer, M. A., Runkle, B. R., and Chaney, R. L. 2024. Mitigating toxic metal exposure through leafy greens: A comprehensive review contrasting cadmium and lead in spinach. *GeoHealth*, **8(6).** https://doi.org/10.1029/2024GH001081
15. Anonymous. 2018a. https://elevationmap.net/chittagong.
16. Anonymous. 2018b. https://www.weatherbase.com/weather/weathersummary.php3?s=87914&cityname=Chittagong%2C+Chittagong%2C+Bangladesh&units=
17. BARC (Bangladesh Agricultural Research Council). 2005. Fertilizer Recommendation Guide. BARC Publication No. 45. Farmgate, Dhaka-1215, Bangladesh.
18. Gachengo, C. N., Palm, C. A., Jama, B., and Othieno, C. 1998. Tithonia and senna green manures and inorganic fertilizers as phosphorus sources for maize in Western Kenya. *Agroforestry systems*, **44(1)**, 21-35. https://doi.org/10.1023/A:1006123404071
19. Day, P. R. 1965. Particle fractionation and particle size analysis. In: Methods of soil analysis. Editor. Black CA. Part I. Agronomy Monograph, Academic Press, New York. 545-567.
20. Jackson, M. L. 1973. Soil Chemical Analysis (New Delhi, Prentice Hall of India Private Limited).
21. Walkley, A., & Black, I. A. 1934. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil science*, **37(1)**, 29-38.
22. Bremner, J. M. 1965. Total Nitrogen 1. Methods of soil analysis. Part 2. Chemical and microbiological properties, (methodsofsoilanb), 1149-1178.
23. Bray, R. H., & Kurtz, L. T. 1945. Determination of total, organic, and available forms of phosphorus in soils. *Soil science*, **59(1)**, 39-46.
24. Jackson, M. L. 1958. Soil chemical analysis. Prentice-Hall, Inc. Englewood Cliffs NJ. p.;45-46.
25. Excel Inc. 2007. Microsoft Excel for Windows, Microsoft Corporation.
26. Islam, M. R., Hossain, M. N., Fakruddin, M., Rabbi, K., and Baten, M. A. 2016. Effect of solid waste slurry from biogas plant on soil parameters and yield of spinach (Spinacia oleracea L.). *Journal of Agriculture and Ecology Research International*, **5(1)**, 1-11.
27. Grameen Shakti. 2006. Field Research Report, Grameen Bank Bhaban, Mirpur, Bangladesh.
28. Bangladesh Agricultural Research Institute (BARI). 2008. Project Report on Bio-slurry management and its effect on soil fertility and crop production. Soil Science Division & On –Farm Research Division, Gazipur, 1701, Bangladesh.
29. Manna, M. C., and Hazra, J. N. 1996. Comparative performance of cow dung slurry, microbial inoculum and inorganic fertilizers on maize. *Journal of the Indian Society of Soil Science*, **44(3)**, 526-528.
30. Qi, X., Zhang, S., Wang, Y., and Wang, R. 2005. Advantages of the integrated pig-biogas-vegetable greenhouse system in North China. *Ecological Engineering*, **24(3)**, 175-183. https://doi:10.1016/j.ecoleng.2004.11.001
31. Messner, H., and Amberger, A. 1987. Composition, nitrification and fertilizing effect of anaerobically fermented slurry. In Agricultural waste management and environmental protection: 4th international CIEC symposium. Szabolcs, I.; Welte, E., Eds.; Braunschweig, Germany, pp.125-130.
32. Dahlberg, S. P., Lindley, J. A., & Giles, J. F. 1988. Effect of anaerobic digestion on nutrient availability from dairy manure. *Transactions of the ASAE*, **31(4)**, 1211-1216.
33. Demuynck, M., Nyns, E. J., and Naveau, H. 1985. Use of digested effluents in agriculture. *Long-term effects of sewage sludge and farm slurries applications. London, Elsevier Applied Science*, 2-13.
34. Juste, C., Dureau, P., and Lasserre, M. 1981. Influence de la digestion méthanique sur la valeur fertilisante de divers déchets organiques. *Compt. Rend. Scean. Acad. Agricul. France*. **6**, 782-790
35. Smith, J. L., and Elliott, L. F. 1990. Tillage and residue management effects on soil organic matter dynamics in semiarid regions. In *Advances in Soil Science: Dryland Agriculture: Strategies for Sustainability Volume 13* (pp. 69-88). Springer, New York, NY. https://doi.org/10.1007/978-1-4613-8982-8_4

36. Prasad, R., and Power, J. F. 1991. Crop residue management. *Adv. Soil Sci*. **15**, 205-251.
37. Pathak, H., Kushwala, J. S., and Jain, M. C. 1992. Evaluation of manurial value of Biogas spent slurry composted with dry mango leaves, wheat straw and rock phosphate on wheat crop. *Journal of Indian Society of Soil Science*, **40**, 753-757.
38. Salyers, A. A., Gupta, A., and Wang, Y. 2004. Human intestinal bacteria as reservoirs for antibiotic resistance genes. *Trends in microbiology*, **12(9)**, 412-416. https://doi.org/10.1016/j.tim.2004.07.004
39. Pang, X. P., and Letey, J. 2000. Organic farming challenge of timing nitrogen availability to crop nitrogen requirements. *Soil Science Society of America Journal*, **64(1)**, 247-253.
40. Berry, P. M., Sylvester-Bradley, R., Philipps, L., Hatch, D. J., Cuttle, S. P., Rayns, F. W., and Gosling, P. 2002. Is the productivity of organic farms restricted by the supply of available nitrogen? *Soil Use and Management*, **18**, 248-255. https://doi.org/10.1111/j.1475-2743.2002.tb00266.x
41. Möller, K., Habermeyer, J., Zinkernagel, V., and Reents, H. J. 2006. Impact and interaction of nitrogen and Phytophthora infestans as yield-limiting and yield-reducing factors in organic potato (Solanum tuberosum L.) crops. *Potato Research*, **49(4)**, 281-301. https://doi.org/10.1007/s11540-007-9024-7
42. Möller, K., Reents, H. J., and Maidl, F. X. 2006. Einfluss von Zwischenfruchtanbau und verschiedenen Saatzeiten von Getreide als Nachfrucht von Kartoffeln auf Nitratdynamik im Boden und das Wachstum von Getreide im ökologischen Landbau. *Pflanzenbauwissenschaften*, **10(2)**, 45-59.
43. Möller, K., and Stinner, W. 2009. Effects of different manuring systems with and without biogas digestion on soil mineral nitrogen content and on gaseous nitrogen losses (ammonia, nitrous oxides). *European Journal of Agronomy*, **30(1)**,1-16. https://doi.org/10.1016/j.eja.2008.06.003
44. Montemurro, F., Canali, S., Convertini, G., Ferri, D., Tittarelli, F., and Vitti, C. 2008. Anaerobic digestates application on fodder crops: effects on plant and soil. *Agrochemica*. **52**, 297-312.
45. Kocar, G. 2008. Anaerobic digesters: From waste to energy crops as an alternative energy source. *Energy Sources, Part A*, **30(7)**, 660-669. https://doi.org/10.1080/00908310600628404
46. Chantigny, M. H., Angers, D. A., Bélanger, G., Rochette, P., Eriksen-Hamel, N., Bittman, S., Buckly, K., Massé, D., and Gasser, M. O. 2008. Yield and nutrient export of grain corn fertilized with raw and treated liquid swine manure. *Agronomy Journal*, **100(5)**, 1303-1309. https://doi.org/10.2134/agronj2007.0361
47. Rivard, C. J., Rodriguez, J. B., Nagle, N. J., Self, J. R., Kay, B. D., Soltanpour, P. N., and Nieves, R. A. 1995. Anaerobic digestion of municipal solid waste: utility of process residues as a soil amendment. *Applied Biochemistry and Biotechnology*, **51(1)**,125-135. https://doi.org/10.1007/BF02933417
48. Marchain, U. 1992. Biogas process for sustainable development. In: FAO Agricultural Service Bulletin 9-5. *Food and Agricultural Organization*: Rome, Italy.
49. Svensson, K., Odlare, M., and Pell, M. 2004. The fertilizing effect of compost and biogas residues from source separated household waste. *The Journal of Agricultural Science*, **142(4)**,461-467. https://doi.org/10.1017/S0021859604004514
50. Möller, K., Stinner, W., Deuker, A., and Leithold, G. 2008. Effects of different manuring systems with and without biogas digestion on nitrogen cycle and crop yield in mixed organic dairy farming systems. *Nutrient cycling in agroecosystems*, **82(3)**,209-232. https://doi.org/10.1007/s10705-008-9196-9
51. Odlare, M., Pell, M., and Svensson, K. 2008. Changes in soil chemical and microbiological properties during 4 years of application of various organic residues. *Waste management*, **28(7)**,1246-1253. https://doi.org/10.1016/j.wasman.2007.06.005
52. Odlare, M. 2005. Organic Residues – A resource to arable soils, Doctoral Thesis, Faculty of Natural Resources and Agricultural Sciences, *Swedish University of Agricultural Sciences,* Uppsala, Sweden.
53. El-Shakweer, M. H. A., El-Sayad, E. A., and Ewees, M. S. A. 1998. Soil and plant analysis as a guide for interpretation of the improvement efficiency of organic conditioners added to different soils in Egypt. *Communications in Soil Science and PlantAnalysis*, **29(**11-14),2067-2088. https://doi.org/10.1080/00103629809370094
54. Clemens, J., Trimborn, M., Weiland, P., and Amon, B. 2006. Mitigation of greenhouse gas emissions by anaerobic digestion of cattle slurry. *Agriculture, ecosystems & environment*, **112(2-3)**,171-177. https://doi.org/10.1016/j.agee.2005.08.016
55. Ernst, G., Müller, A., Göhler, H., and Emmerling, C. 2008. C and N turnover of fermented residues from biogas plants in soil in the presence of three different earthworm species (*Lumbricus terrestris, Aporrectodea longa, Aporrectodea caliginosa*). *Soil Biology and Biochemistry*, **40(6)**, 1413-1420. https://doi.org/10.1016/j.soilbio.2007.12.026