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*RESEARCH ARTICLE*

# EFFECT OF BIOGAS SLURRY ON COMPOSTING PROCESS AND QUALITY OF CATTLE MANURE-BASED COMPOST AND VERMICOMPOST

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## Abstract

Regarding the increasing demand of good organic manure, we made an attempt to generate a modified vermicompost from biogas slurry amended cattle manure. For this, six trials including control were run in pots by adding 2−10% (w/w, fw.) biogas slurry to cattle manure for 21 days for composting and 60 days for vermicomposting using *E. eugeniae* earthworms (10 per 500 g) under aerobic condition keeping moisture level of 70±5% within the overall temperature range of 13−39°C. The use of bacterial inoculants increased the agricultural quality of the compost and accelerated the composting process. After being maturity, pH of the vermicompost reached to 7.66, indicating that it has excellent nutrient releasing capability. Since EC of the produced vermicompost is less than 1.60 dS $m^{-1}$, it has high cation-exchange capacity, which is beneficial to soil texture and plant health. An increment in 163% of available P in the vermicompost (6.35 ± 0.78 mg $g^{-1}$, dw) than that in the compost and the highest increment of 264% with respect to control indicated that it was a better organic fertilizer and hence might be an alternative to $P_2O_5$. The worm-processed material for trials $T_1$-$T_5$ showed 10.0–32.5% more exchangeable K than control ($T_0$). An increment of 43.84% in total N and an decrease of 15.6% in total organic C makes the vermicompost ideal for use for its lowest C:N ratio of 15:1, whereas it was 35:1 in compost. Each of the N-P-K contents was elevated significantly that made it a potential organic fertilizer. Comparison of the key parameters with vermicomposts of buffalo, pig, goat, horse, chicken and sheep manures of different countries confirms that the produced vermicompost could serve as an excellent organic manure.



## Introduction:-

In order to ensure world food security by World Food Program (WFP), modern agricultural farming practices use of excessive chemical inputs over decades to increase crop production. According to the United Nations Environment Program (UNEP) [1], fertilizer market is growing by 4.1% per year. The use of several inorganic fertilizers strongly increased between 1961 and 2019. Food and Agriculture Organization (FAO) [2] estimated that starting from 10 million tons in 1961, nitrogen (N), phosphorus (as $P_2O_5$) and potassium (as $K_2O$) increased to 110, 45 and 35 million tons respectively in 2021.

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There is no doubt that chemical fertilizers containing N, P and K increase the output of agricultural products. But the continuous practice of excessive use of inorganic fertilizers imparts negative effects on soil heath, environmental pollution prevention, natural eco-system and food quality. Soil health deteriorates to a great extent due to declination of soil organic matter (SOM) content, depletion of beneficial microorganisms and salinization of soil for salt gathering [3]. The concerned environmental pollution includes soil erosion, groundwater contamination through leaching and eutrophication of fresh water system [1]. Adverse impacts are also noticed in bird population and aquatic organisms along with biodiversity loss. Moreover, the excessive and inefficient use of pesticides kills approximately 11,000 people every year [1].

At present, the agricultural land is diminishing exorbitantly, whereas the world population is increasing with respect to time. To combat the situation, FAO (2017) [4] has set '*Voluntary Guidelines for Sustainable Soil Management*' that mainly emphasizes the application of organic fertilizers with *4R Nutrient Stewardship*. Organic agriculture is a holistic production management system which promotes and enhances agro-ecosystem health, including biodiversity, biological cycles and soil biological activity. It emphasizes the use of management practices in preference to the use of off-farm inputs, taking into account that regional conditions require locally adapted systems. This is accomplished by using wherever possible, agronomic, biological and mechanical methods, as opposed to using synthetic materials, to fulfill any specific function within the system [5].

Organic manures generally improve the soil physical, chemical and biological properties along with conserving the moisture holding capacity of soil and thus enhance crop productivity along with maintaining the quality of the food generated. However, most of the organic manures are very low in nutrient contents, which are not sufficient to meet the total nutritional requirement of the crops, especially when inorganic fertilizers are not applied [6]. To improve nutrient content permitted additives like rock phosphate, beneficial microbial cultures and neem cake could be used as nutrient supplements [7].

Several animal manures, namely, cattle or donkey or horse or pig dung could serve as organic manures when composted properly through biodegradation by the action of microorganisms. Zeng et al. (2009) [8] and Figueiredo et al. (2013) [9] found that the use of microbial inoculants accelerated the composting process and improved the final product. But those were not up to the total requirement of the nutrients.

In order to meet the nutritional requirement of organic fertilizer, we made an attempt to use Biogas Slurry (BGS), a by-product of anaerobic digestion, as an organic additive (an inoculant) to cattle manure. Because BGS has roughly three times the N-P-K of the compost [10-11] and its beneficial methanogenic and non-methanogenic bacteria [12] would elevate the N-P-K content through microbial processes. We further advanced to vermicomposting using African Nightcrawler (*Eudrilus eugeniae*) earthworms to generate the finest and nutrient-rich organic fertilizer to address UNEP/FAO search for a new potential fertilizer for a sustainable agriculture. We also made an attempt to quicken the composting/vermicomposting process to prevent the nutritional loss. If the physico-chemical analyses and proper quality evaluation of the generated final organic fertilizer through C:N ratio or N-P-K ratio along with other comparison could lead it to a noble and potential organic fertilizer, then it would be regarded as a milestone in agricultural sector.

## Materials and Methods:-

### *2.1 Materials*

All the chemicals used in the investigation were of high purity analytical grade that were used without further purification. The substrates, cattle manure (CM) and biogas slurry (BGS), were collected from an agricultural project of University of Rajshahi, Bangladesh. The raw CM and BGS were thoroughly homogenized separately prior to use for composting. A collection of healthy, purple-grey sheen earthworms, named African Nightcrawler (*Eudrilus eugeniae*), were collected from a vermicomposting farm situated in Paba of Rajshahi, Bangladesh.

### *2.2. Experimental Setup*

Six experimental trials, namely, $T_0$ (Control), $T_1$, $T_2$, $T_3$, $T_4$ and $T_5$ were constructed by adding 0, 2, 4, 6, 8 and 10% (w/w, fw.) of BGS to CM (Table 1). These were mixed thoroughly and kept in separate air tight polythene bags. The composting samples from different trials were collected on $1^{st}$, $7^{th}$, $14^{th}$ and $21^{st}$ day of composting process, that is, from commencement.

**Table 1:-** Experimental set-up for cattle manure (CM) and biogas slurry (BGS) for composting.

| Trial | CM (kg, fw.) | BGS (kg, fw.) | CM:BGS | Moisture content (%) |
|---|---|---|---|---|
| $T_0$ (Control) | 10.00 | 0.00 | 100:00 | 70.5 |
| $T_1$ | 9.80 | 0.20 | 98:2 | 70.7 |
| $T_2$ | 9.60 | 0.40 | 96:4 | 70.9 |
| $T_3$ | 9.40 | 0.60 | 94:6 | 71.1 |
| $T_4$ | 9.20 | 0.80 | 92:8 | 71.3 |
| $T_5$ | 9.00 | 1.00 | 90:10 | 71.5 |

The substrates for vermicompost were then air dried for two days (for proper weighing) followed by adding requisite amount of distilled water homogeneously to confirm desired moisture level. The generated mixtures were then filled in plastic circular containers of appropriate size (28 cm diameter and 30 cm in depth) with pierced lids for aeration for vermicompost preparation. Ten earthworms *E. eugeniae* were released into each plastic pot container containing 500 g (dry weight basis) of the prepared compost. The moisture level of all substrates in vermibeds was maintained 70±5%, throughout the study period (24-60 days of commencement) by periodic sprinkling of adequate quantity of distilled water. The experimental containers were placed in a humid and dark room having the maximum and the minimum temperature ranges of 23−39°C and 13−28°C respectively. For sampling purposes, both compost and vermicompost were oven dried for 48 h at 60°C followed by grinding in stainless steel blender and stored in sterilized plastic airtight containers for physiochemical analysis [13].

### 2.3. Physico-chemical Analysis

The physicochemical analyses of BGS amended CM-based compost and vermicompost were carried out using standard procedures for the followings:

#### 2.3.1. Determination of Physical Parameters

Moisture content and total solid (TS) of fresh substrate were estimated by gravimetric method of US Environment Protection Agency (USEPA) [14] by drying at 105°C for 12 h in an oven, whereas volatile solid (VS) of dried substrate by complete combustion at 400°C for six hours in a muffle furnace [15].

Prior to measure pH and Electrical Conductivity (EC), the solid substrate was allowed to mix with Distilled Deionized Water (DDW) in the ratio of 10:25 (w/v) continuously with magnetic stirrer for 30 min to make a homogeneous suspension [16]. A microprocessor controlled pH meter (Jenway, England, model 3030), having ATC mode and capable of capable of reading up to two decimal places with an accuracy of ± 0.01 unit, was employed to check the pH values. EC was also measured with a conductivity meter (Jenway Conductivity Meter, England, model 4310) that was calibrated by determining cell constant (l/A) with 0.10 M and 0.01 M standard KCl solutions at the experimental temperature.

Total Organic Carbon (TOC) was determined by loss of ignition (LOI) method (Schumacher, 2002) that involved in the heated destruction of all organic matters in the sample. A known weight of oven dried sample was placed in a ceramic crucible which was then heated at 400°C for 6 h in a muffle furnace [15] followed by cooling and weighing after gaining constant weight. Organic matter (OM) content (g $kg^{-1}$) was calculated as the difference between the initial and final sample weights divided by the initial sample weight times 1000. OM was multiplied by 0.5 to obtained TOC [17].

#### 2.3.2. Estimation of Chemical Parameters

Total nitrogen ($N_{tot}$) was measured using modified Kjeldahl method of FAO [18]. A 1.0 g of dried sample was digested at 320–370°C with 0.7 g of copper sulphate, 1.5 g of $K_2SO_4$ and 30 mL of conc. $H_2SO_4$ (98%) in a Kjeldahl flask until the solution became clear. At the end of digestion, the solution was distilled with 35% NaOH solution and the distillate was collected in excess 0.1 M HCl solution containing methyl red indicator. The excess HCl was titrated with 0.1 M NaOH solution. The amount of nitrogen in the sample was calculated from the required volume of HCl solution.

Available phosphorous ($P_{avail}$) was measured by the method described by USDA [19]. A 5.0 g of dried sample was shaken with 100 mL of the 0.5 M $NaHCO_3$ solution and 1 teaspoon carbon black to make the solution clear. The mixture was filtered using Whatman filter paper. The filtrates were analyzed following the reported method [20] using a high-resolution, real-time scanning UV-visible spectrophotometer with background corrector (UV-1800, SHIMADZU).

Exchangeable potassium ($K_{exch}$) was determined after extracting the sample using ammonium acetate [21] followed by dilution and analysis by GF-AAS with a Shimadzu AA-6800 (Shomadzu Corporation, Kyoto, Japan) atomic absorption spectrophotometer. It was equipped with an auto-sampler (ASC-6100, Shimadzu) and a graphite furnace (GFA-EX7, Shimadzu), and operated through '*WizAArd*' Software.

### *2.4. Quality Control (QC)*

All glassware were treated with 10% (v/v) $HNO_3$ for 24 h and then rinsed with DDW followed by drying in an oven. Certified reference materials (CRM) of Fluka, Switzerland were employed for calibration purposes. The chemical analysis was carried out following the United States Environmental Protection Agency (USEPA) approved Quality Assurance/Quality Control (QA/QC) plan with a reagent blank, a duplicate and a spike for every 20 samples. After analyzing every 10 samples, readings of standard solutions were recorded to check the instrument. One certified reference material of Lake Sediment (NIES 31) was digested and analyzed in five replicates under the identical experimental conditions to check the accuracy of the method. It is to be noted that the experimental bedding were kept in triplicate for each treatment. Moisture, temperature and other parameters were controlled according to USDA Organic Regulations for Organic Compost [22].

### *2.5. Statistical Analysis*

The datasets obtained for both compost and vermocompost were treated separately for analyzing basic statistical parameters and for making cross-tabulations and cross-plots. The SPSS (release 20.0), STATGRAPHICS Centurion (release 18.1.01) and Microsoft Excel (release 12.0) were employed for the purpose. ANOVA and Levene's Variance tests were employed for analyses of variance of the data (Table 4). Kruskal-Wallis and Mood's median tests were also employed for analyses of median of the data.

### *2.6. Comparison of the Fertilizers*

The evaluation of the quality of the produced fertilizers was made based on TOC, C:N ratio and N-P-K ratio. A few of similar global fertilizers were also compared with those based on the combined or individual parameters mentioned above.

## Results and Discussion:-

### 3.1 Statistical Analyses of the Parameters

The statistical analyses of the observed nutrient concentrations and the physical parameters of different trails (control, $T_0$ and $T_1$–$T_5$) for both compost and vermicompost (n=156) are presented in Table 2. The mature compost and vermicompost are correspond to 21st and 60th day of commencement of BGS addition to CM respectively. The statistical analyses (Table 3) reveal that the mean values found for compost and vermicompost respectively were 1,832 and 1,533 µS $cm^{-1}$ for EC, 8.25 and 7.66 for pH, 327.4 and 276.3 mg $g^{-1}$ (dw) for TOC, 9.33 and 13.42 mg $g^{-1}$ (dw) for $N_{tot}$, 2.41 and 6.35 mg $g^{-1}$ (dw) for $P_{avail,}$ 8.50 and 9.43 mg $g^{-1}$ (dw) for $K_{exch}$ and 35.33 and 21:1 for C:N ratio. These are in accordance with the findings of compost fertilizer of many authors [23-24].

**Table 2:-** The mean parameter values for different compost and vermicompost trials.

| Trial | Sample | Mean parameter value | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | pH | EC (µS $cm^{-1}$) | TOC (mg $g^{-1}$, dw) | $N_{tot}$ (mg $g^{-1}$, dw) | $P_{avail}$ (mg $g^{-1}$, dw) | $K_{exch}$ (mg $g^{-1}$, dw) | C:N ratio |
| $T_0$ [a] | Compost[b] | 8.27 | 1770 | 321.3 | 9.1 | 2.56 | 8.1 | 35.3:1 |
| | Vermicompost[c] | 7.71 | 1453 | 268.8 | 14.7 | 6.98 | 8.0 | 18.3:1 |
| $T_1$ | Compost | 8.15 | 1863 | 333.7 | 9.8 | 3.10 | 8.5 | 34.0:1 |
| | Vermicompost | 7.52 | 1595 | 275.7 | 15.4 | 9.31 | 10.3 | 17.9:1 |
| $T_2$ | Compost | 8.21 | 1882 | 330.7 | 9.8 | 2.67 | 8.6 | 33.7:1 |
| | Vermicompost | 7.40 | 1630 | 274.6 | 17.5 | 7.28 | 10.6 | 15.7:1 |
| $T_3$ | Compost | 8.30 | 1851 | 325.5 | 8.4 | 2.38 | 8.9 | 38.8:1 |
| | Vermicompost | 7.68 | 1491 | 274.2 | 9.1 | 5.18 | 9.3 | 30.1:1 |
| $T_4$ | Compost | 8.30 | 1846 | 331.5 | 8.4 | 2.05 | 7.8 | 39.5:1 |
| | Vermicompost | 7.80 | 1527 | 287.7 | 11.2 | 5.43 | 8.8 | 25.7:1 |
| $T_5$ | Compost | 8.29 | 1777 | 321.9 | 10.5 | 1.69 | 9.1 | 30.7:1 |
| | Vermicompost | 7.87 | 1505 | 277.0 | 12.6 | 3.92 | 9.6 | 22.0:1 |

[a] $T_0$ corresponds to the control; [b] Composting duration corresponds to 21st day of commencement; [c] Vermicomposting duration corresponds to 60th day of commencement

**Table 3:-** Statistical analyses of nutrient contents and other parameters of compost and vermicompost of different trials.

| Para-meter | Sample | Nutrient Concentration (mg $g^{-1}$, dw) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Range (Min -Max) | Mean ± SE | 95% CI for mean | Median | Standard Deviation | Variance | Skewness |
| EC[a] | Compost | 1770 - 1882 | 1832 ± 19 | 1782 - 1880 | 1848 | 46 | 2177 | -0.661 |
| | Vermicompost | 1453 - 1630 | 1533 ± 27 | 1463 - 1603 | 1516 | 67 | 4447 | 0.515 |
| pH[a] | Compost | 8.15 - 8.30 | 8.25 ± 0.02 | 8.19 - 8.32 | 8.28 | 0.06 | 0.004 | -1.233 |
| | Vermicompost | 7.40 - 7.87 | 7.66 ± 0.07 | 7.48 - 7.85 | 7.69 | 0.17 | 0.031 | -0.541 |
| TOC[b] | Compost | 321.3 - 333.7 | 327.4 ± 2.1 | 321.9 - 333.0 | 328.1 | 5.26 | 27.69 | -0.122 |
| | Vermicompost | 268.8 - 287.7 | 276.3 ± 2.5 | 269.8 - 282.9 | 275.1 | 6.23 | 38.87 | 1.270 |
| $N_{tot}$ | Compost | 8.40 - 10.50 | 9.33 ± 0.35 | 8.44 - 10.22 | 9.45 | 0.848 | 0.719 | 0.075 |
| | Vermicompost | 9.10 - 17.50 | 13.42 ± 1.24 | 10.22 - 16.62 | 13.65 | 3.049 | 9.294 | -0.147 |
| $P_{avail}$ | Compost | 1.69 - 3.10 | 2.41 ± 0.20 | 1.89 - 2.92 | 2.47 | 0.493 | 0.243 | -0.161 |
| | Vermicompost | 3.92 - 9.31 | 6.35 ± 0.78 | 4.35 - 8.35 | 6.20 | 1.904 | 3.629 | 0.445 |
| $K_{exch}$ | Compost | 7.80 - 9.10 | 8.50 ± 0.19 | 7.99 - 9.01 | 8.55 | 0.486 | 0.236 | -0.330 |
| | Vermicompost | 8.00 - 10.60 | 9.43 ± 0.39 | 8.42 - 10.44 | 9.45 | 0.961 | 0.923 | -0.324 |
| C:N[c] ratio | Compost | 30.70 - 39.50 | 35.33 ± 1.36 | 31.84 - 38.82 | 34.65 | 3.325 | 11.059 | 0.064 |
| | Vermicompost | 15.70 - 30.10 | 21.62 ± 2.23 | 15.89 - 27.34 | 20.15 | 5.452 | 29.722 | 0.710 |

[a] EC is measured in µS $cm^{-1}$ and pH is unitless
[b] TOC stands for Total Organic Carbon
[c] The ratio of 1 is not shown for the sake of simplicity

The *ANOVA* table (Table 4) decomposes the variance of the data into two components**:** a between-group component and a within-group component. The F-ratio, which in this case equals 4497.96, is a ratio of the between-group estimate to the within-group estimate. Since the *P*-value of the F-test is less than 0.05, there is a statistically significant difference between the means of the variables at the 5% significance level. Since the *P*-values of *Levene's Variance Test* (Test statistic = 14.3961) and *Kruskal-Wallis Test* (Test statistic = 79.9696) is less than 0.05, there is a statistically significant difference amongst the standard deviations and medians at the 95.0% confidence level respectively for 14 columns. Finally, as the *P*-value of *Mood's Median Test* (Test statistic = 77.3333) is less than 0.05, the medians of the samples are significantly different at the 95.0% confidence level.

**Table 4:-** The ANOVA table for the studied parameters, each in two groups.

| **Source** | **Sum of squares** | **Df** | **Mean square** | **F-ratio** | ***P*-value** |
|---|---|---|---|---|---|
| Between groups | 2.81785E7 | 13 | 2.16757E6 | 4497.96 | < 0.001 |
| Within groups | 33733.1 | 70 | 481.901 | | |
| Total (Corr.) | 2.82122E7 | 83 | | | |

### 3.2 Physicochemical Properties of Compost and Vermicompost

#### 3.2.1 pH

The pH acts a major factor in governing the microbial induced decomposition processes of organic matter [25] and release of the nutrients [26]. Whereas the most of the authors such as Zhang and Sun [27] reported the range of pH between 7 and 8 for the optimal microbial activity for the decomposition of organic matter during composting process, it is claimed as near neutral range of pH by a few authors such as Karnchanawong and Suriyanon [28].

In the present study, the pH showed an increasing pattern during the composting process as illustrated in Fig 1a. The increasing rate of pH for BGS treated trials ($T_1$-$T_5$) was low for first 14 days (averagely from 7.57 to 7.77) followed by rapid increase (averagely from 7.77 to 8.25) for the last 7 days. This is attributed to the reduced microbial assisted acid ($H_2SO_4$) production due to lower sulfur content in substrate and production of $CO_2$, ammonia, $NO_3^-$ and other intermediate species of the organic acids by microbial decomposition [29]. The control trial ($T_0$) pH was found to increase steadily over the composting period perhaps due to higher buffering capacity of bulking agents avoiding further pH fluctuation [30].

During vermicomposting, the pH was decreased slightly from 7.71 to 7.65, on an average, towards stabilization of the fertilizer. Therefore, the generated vermicompost was slightly alkaline in nature with excellent nutrient releasing capability, especially for Ca, Mg and Mo [31-33]. The additional benefit of the fertilizer is that it can be employed to treat the slightly acidic soils, caused by acid rain or other processes, without the addition of lime or gypsum.

### 3.2.2 Electrical Conductivity

Electrical conductivity (EC) measures the ability of compost or vermicompost adhered water to carry electrical current. Since the dissolved cations (such as $Ca^{2+}$, $Mg^{2+}$, $Na^{+}$, $K^{+}$ and $NH_4^{+}$) and anions (such as $SO_4^{2-}$, $Cl^{-}$, $NO_3^{-}$ and $HCO_3^{-}$) are responsible for the electric current, EC is a potential measure of the combined amount of salts, that is, salinity of the compost or vermicompost. The greater the concentration of soluble salts in the fertilizer, the greater will be the electrical conductance.

We found that EC of the samples during composting process over a span of 21 days varied from 1598 to 1882 μS $cm^{-1}$ (Fig 1b). Compared to the initial values, the final EC for the composting product for all runs showed an increase of 2.9, 6.8, 9.0, 13.4, 11.2 and 11.2% in $T_0$, $T_1$, $T_2$, $T_3$, $T_4$ and $T_5$, respectively. This can be explained as mineral ion concentration increases with the decomposition of organic materials and is not reduced by binding to stable organic complex [28]. For vermicompost process, EC value decreased to 1533 ± 27 μS $cm^{-1}$ (or, 1.53 ± 0.03 dS $m^{-1}$), on an average, after maturation of the fertilizer. Obviously, the BGS amended CM composts were moderately saline, whereas the generated vermicpmpost slightly saline.

Since EC of the produced vermicompost is less than 1.60 dS $m^{-1}$, therefore it serves as an excellent fertilizer for nutrient availability, soil texture and plant health for high cation-exchange capacity (CEC), according to US Department of Agriculture [34]. Upon comparison, the studied vermicompost is better than the corresponding compost.

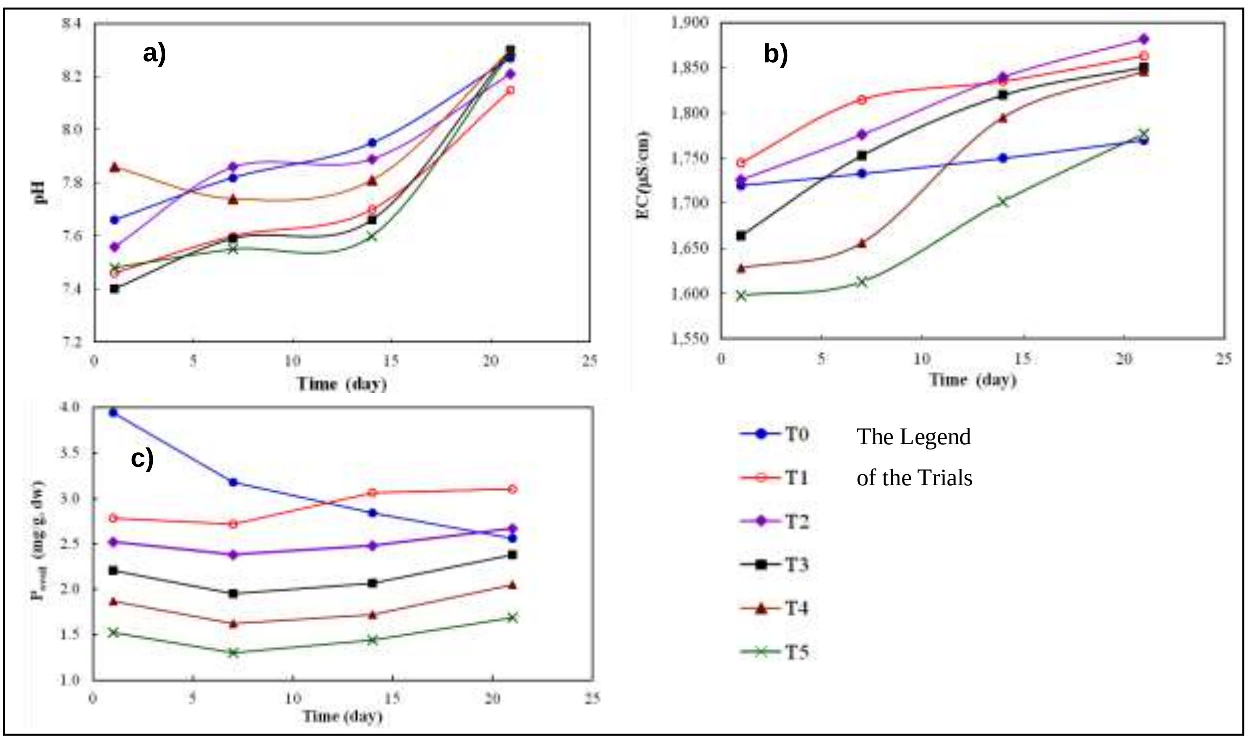



**Fig 1:-** Average change of pH, electrical conductivity and available P during composting.

### 3.2.3 Available Phosphorus

The available phosphorus concentrations ($P_{avail}$) were found to decrease initially (from average 2.47 to 2.19 mg $g^{-1}$) and then to increase steadily up to average 2.41 mg $g^{-1}$ for the trials with compost except for the control ($T_0$) (Fig 1c). This might be due to two competing process − (i) conversion to microbial P for microbial biomass increase and deposition of insoluble calcium phosphate under slightly alkaline environment [35], and (ii) decomposition of organic matter that increase the concentration of available phosphorus. Process (i) is believed to predominate over process (ii) for trials $T_1$-$T_5$ within the first 7 days, whereas process (ii) predominate for the rest period. Our findings in composting process are also in accordance with Duian et al. [36].

For vermicomposting process, the $P_{avail}$ was found to increase up to 9.31 mg $g^{-1}$ (dw.), averaging the value of 6.35 ± 0.78 mg $g^{-1}$ (dw.). Phosphatases, a key enzyme in the P cycle, are the extracellular enzymes that catalyze the hydrolysis of phospho-ester bonds in organic P-containing substrates releasing inorganic P in the form of orthophosphates [37]. An increment in 163% of $P_{avail}$ in the vermicompost than in the compost indicates that the generated vermicompost is a better organic fertilizer and hence an alternative to $P_2O_5$.

### 3.2.4 Exchangeable Potassium

The exchangeable potassium ($K_{exch}$) content was found higher (8.0–10.6 mg $g^{-1}$, dw.) in vermicomposted materials than the initial corresponding composted level (7.8–9.1 mg $g^{-1}$, dw.) (Table 3). The worm-processed material for trials $T_1$-$T_5$ showed 10.0–32.5% more exchangeable K than control ($T_0$). The maximum increase in $K_{exch}$ content was observed in $T_2$ (32.5%) followed by $T_1$(28.8%), $T_5$ (20.0%), $T_3$(16.3%) and $T_4$ (10.0%). Kale et al. [38] concluded that when organic waste passes through the gut of worm, some organic forms of nutrients are then converted into more plant available forms (i.e., in inorganic forms). The findings are in good agreement with the fact that the vermicomposting process accelerated the microbial populations in waste that subsequently enriched the end product with more available forms of plant nutrients.

### 3.2.5 Total Organic Carbon

While the compost was being prepared, the level of TOC was elevated averaging the value of 327.4 ± 2.1 mg $g^{-1}$, dw. But during vermicomposting process, the TOC level was declined to 276.3 ± 2.5 mg $g^{-1}$, dw., estimating 15.6%. This is the general observation for vermicompost preparation. This is due to containing a small amount of cellulose in the final fertilizer for microorganism, especially earthworm-gut bacteria, assisted bio-degradation.

### 3.2.6 Total Nitrogen

The total nitrogen content ($N_{tot}$) was found to increase in both of the compost and vermicompost. Whereas $N_{tot}$ was increased from the control value of 9.1 mg $g^{-1}$, dw. up to 10.5 mg $g^{-1}$, dw. for compost, it was further increased to 15.4 mg $g^{-1}$, dw. for vermicompost (Table 2). Comparison of the average values of $N_{tot}$ reflects in an increment of 43.84% that reveals that BGS amended cattle manure produce a better vermicompost than compost. Several nitrogenous ions, e.g., $NH_4^+$, $NO_2^-$ and $NO_3^-$ along with many gases, e.g., $NH_3$, $N_2O$ and $N_2$ are produced in vermicomposting process (Fig 2). But the increment of $N_{tot}$ in the fertilizer is due to a combination of fragmentation in plant residue, fixation of atmospheric nitrogen and addition of earthworm's metabolic and excretory (vermicast), mucus, body fluid and enzymes [39].

### 3.3 Probable Mechanism of Vermicomposting

The vermicomposting process follows a complication mechanism in which a lot of physical, chemical and micro-biological parameters are involved actively. Conversion of nitrogenous, phosphorous, carbon, etc. along with cation and anion exchange are common. Most of the process are discussed in the previous sections and depicted in Fig 2.

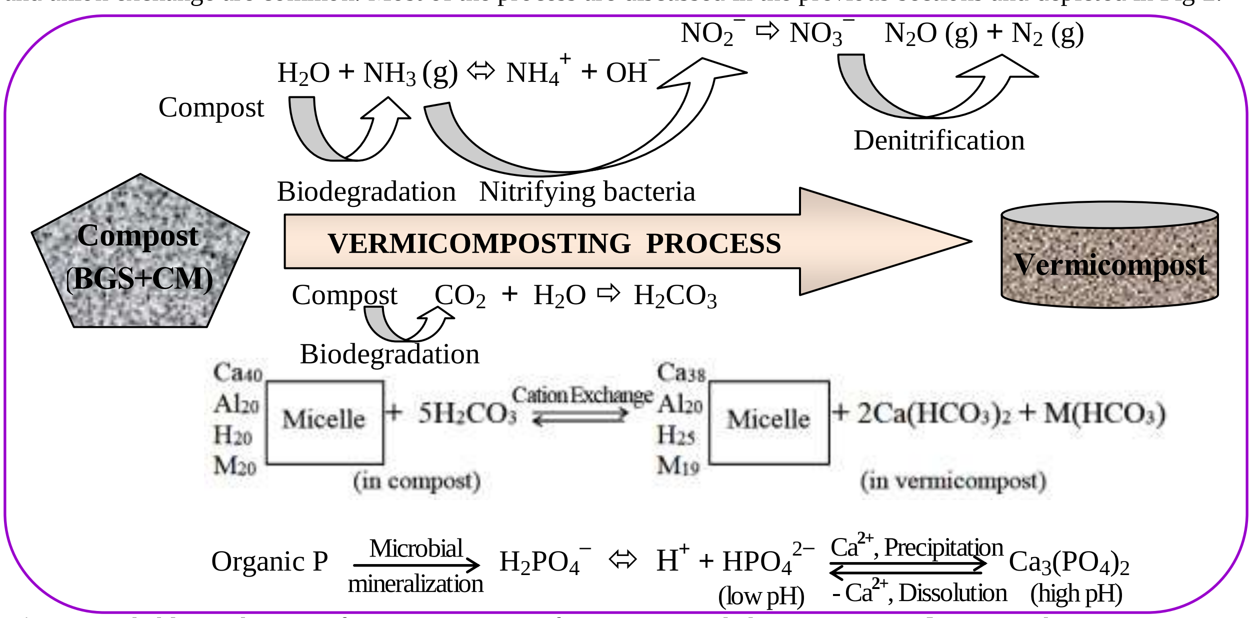



**Fig 2:-** Probable mechanism of vermocomposting from CM amended BGS compost. [Anion exchange reactions are not shown here]

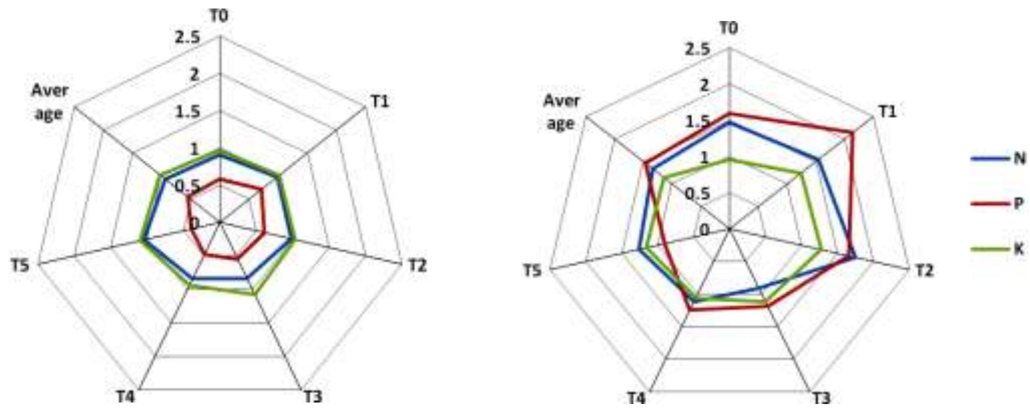
### 3.4 Assessment of the Quality of the Organic Fertilizers

#### 3.4.1 C:N Ratio

The carbon to nitrogen ratio (C:N ratio), a parameter of organic manure quality, of the generated composts and vermicomposts of different trials were estimated throughout. According to the FAO (2015) guideline [40], the C:N ratio of the initial substrate should be 25:1 − 40:1 for the composting process because soil microorganisms need to burn carbon as a source of energy to produce $CO_2$. But they suggested the C:N ratio of final vermicompost at around 15:1. In the present study, in the composting process the C:N ratio was found to decrease with respect to control (35:1) up to 30:1. In the vermicomposting process, the C:N ratio decreased further greatly (up to 15:1) leading to both idealness and maturity of the organic fertilizer. The lower C:N ratio of vermicomposted material than experimental control (18:1) suggested the earthworm mediated waste mineralization and formation of plant consumable nitrogenous anions. It is to be noted that if the studies substrates would be of less alkaline, loss of nitrogen as ammonia would be prevented. Since the C:N ratio of below 20 is indicative of acceptable maturity and 15 or lower being preferable for agronomic use of composts [41], the BGS amended cattle manure compost derived vermicomposts have the potentials of effective agronomic.

#### 3.4.2 N-P-K Ratio

The nitrogen-phosphorus-potassium (N-P-K) content ratio is also another parameter to understand the quality of an organic fertilizer. All the parameters were improved in the vermicompost than the corresponding compost (Table 3). The individual contents were discussed in the previous sections and the overall N-P-K scenario is depicted in Fig 3.




**a) Compost** **b) Vermicompost**

**Fig 3:-** Change in %N, $\%P_2O_5$ and $\%K_2O$ concentrations for N-P-K ratios of different trials.

### 3.5 Comparison with Other Types of Vermicomposts

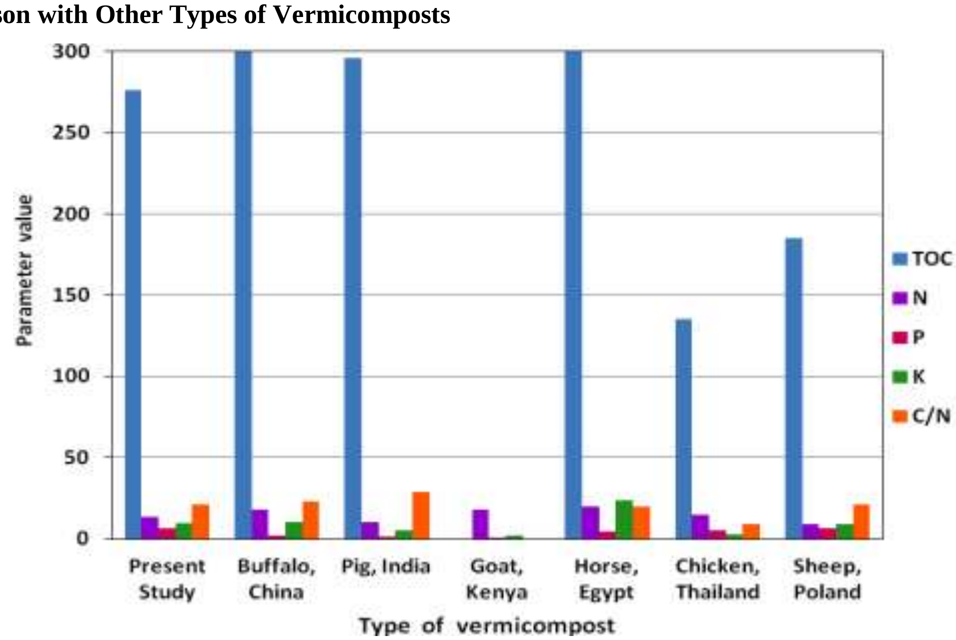



**Fig 4:-** Comparison of the produced vermicompost with other types of vermocomposts. (Buffalo and Horse TOC are out of the range) [42-47]

In order to understand the potentiality of the generated vermicompost, we made an attempt to compare it with other types of vermicomposts of the world [42-47]. These include vermicomposts of buffalo (China), pig (India), goat (Kenya), horse (Egypt), chicken (Thailand) and sheep (Poland) manures. For comparison purpose, the key parameters chosen included TOC, $N_{tot}$, $P_{avail}$, $K_{exch}$ and C:N ratio. It is obvious from Fig 4 that our BGS amended cattle manure vermicompost is fairly comparable with those, even in some cases it is better.

## Conclusions:-

Though natural organic manures are eco-friendly and good for soil health, those are unable to satisfy the total demand of plant nutrients, especially N-P-K contents. Regarding this, we made an attempt to generate a modified vermicompost from BGS amended CM. For this, six trials $T_0$ (control), $T_1$, $T_2$, $T_3$, $T_4$ and $T_5$ were run in pots by adding 0, 2, 4, 6, 8 and 10% (w/w, fw.) biogas slurry to cattle manure for 21 days for composting and 60 days for vermicomposting using *Eudrilus eugeniae* earthworms as ten per 500 g under aerobic condition keeping moisture level of 70±5%. The use of bacterial inoculants increased the agricultural quality of the compost and accelerated the composting process. During composting process, pH was increased rapidly to 8.25 followed by steadily decreased in vermicomposting process to 7.66. Hence, the slightly alkaline vermicompost has excellent nutrient releasing capability and beneficial to acidic soil. Since EC of the produced vermicompost is less than 1.60 dS $m^{-1}$, it can serve as an excellent fertilizer for nutrient availability, soil texture and plant health for high CEC. An increment in 163% of available P in the vermicompost (6.35 ± 0.78 mg $g^{-1}$, dw) than that in the compost and the highest increment of 264% with respect to control indicated that it was a better organic fertilizer. The worm-processed material for trials $T_1$-$T_5$ showed 10.0–32.5% more exchangeable K than control ($T_0$). An increment of 43.84% in total N and an decrease of 15.6% in total organic C makes the vermicompost ideal for use for its lowest C:N ratio of 15:1, whereas it was 35:1 in compost. The significant elevation of each of the N-P-K content making the vermicompost a partial replacement of inorganic fertilizers. Comparison of the key parameters with vermicomposts of buffalo, pig, goat, horse, chicken and sheep manures of different countries confirms that the produced vermicompost could be an excellent organic manure.

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