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Ecological sanitation: relative efficiency of different composting materials and recovery of nutrients for eco-san toilets

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Abstract

Human waste disposal practices are fivefold: open air defecation, dry latrines, eco-san toilet, pit latrines and septic tank toilet. Of which ecological sanitation is an advanced and sustainable method of managing human excreta, by means of recovering nutrients in both urine and faeces. Ecological sanitation envisages a scientific mechanism for a value addition to human excreta by attaching economic value to it. Predominately wood ash was used as composting material, however locally available various different composting materials also have the potential to compost human waste. There are differences among the materials in time taken to composting and nutrient recovery efficiency. Materials engaged for composting included wood ash, dry earth soil, saw husk and rice husk for the experiments conducted in the study. The experimental procedure was to spread the above composting material on faecal matter and provide anaerobic condition for six to ten months for composting. The present paper deals with the material which performs better than the others in nutrient recovery and reducing the time period of composting. In this regard the use of dry earth soil was found more efficient in producing standard physiochemical and biological parameters of the organic manure. From the results it has been confirmed that the E.coli gradually decreased to nil in just span of six months. Interestingly, the nutrient values of the total nitrogen, phosphorous and potassium (NPK) showed a lower level in the beginning state of composting but eventually at the final stage of composting after one year it had increased when using the wood ash, saw husk and rice husk. Presence of heavy metals were tested after the 10th month for all the above composting materials and the result for Cu, Cr, Zn, Pb, Ni, and Cd were observed to be within the permissible limit of Indian compost standard and Cd, As, and Hg was recorded Below Detectable Limit (BDL).

Keywords: Ecological Sanitation, Human waste, Composting, Nutrients.

Introduction

Water, sanitation and hygiene (WASH) are indispensable for human health and welfare. In addition, an increase in access to sanitation will lead to better school enrolment and increased economic productivity. Conversely, poor sanitation proved to be a strong risk factor for mortality of children worldwide. Lack of access to potable water causing diarrheal death was estimated to be 5.02 lakh and 2.8 lakh death due to insanitation. Besides, neglect of personal hygiene like hand wash and the disease burden fall out was estimated at 2.97 lakh deaths. Proper sanitation and provision of safe drinking water could prevent the death of 3.61 lakh children below five years of age[1]. The WHO data supports the point that globally 6,22,000 children with less than five years of age faced loss of life owing to diarrhoeal disease. Approximately it works out to be 4,100 deaths each day with a school day loss of 443 million for want of safe drinking water[2,3].

It is evident that above fifty percent of the global population enjoy toilet facility for human excreta disposal. There are numerous sanitation models in vogue, *inter alia*, there exist 'flush-and-discharge', 'flush-and forget', 'drop and store', and 'sanitize and reuse'[4-7]. Flush toilets and the sewage thereof are disposed of into environmental medium mostly devoid of treatment. Despite these sanitation models having positive spill over, excepting 'Sanitize-and-reuse', other models cause loss of human well being with financial and ecological implications[8-10]. Eco-san toilets may be categorized under 'Sanitize-and-reuse', which is central to this paper. Reviews by Esrey et. al, showed a 16 percent to 25 percent reduction in diarrhoeal death in response to provision of good potable water. Further, Esrey's evidenced the health implications owing to in sanitation[11]: as high as 21 studies out of 30 stood as testimony for reduction in diarrheal diseases with improved excreta disposal, in general and flush toilets in particular. In addition, pit latrines were contributing positively with reduced morbidity. Feachem and Koblinsky observed a fall in diarrhoeal ailment of 32-43 percent through hand washing with soap in different settings[12]. Boot and Caincross showed that awareness of personal hygiene helped reducing diseases to the extent of 30-48 percent[13]. Therefore, strategies to encourage Hand washing practice could bring down diarrhoeal problem substantially[14]. Additionally in 2010, the United Nations general assembly in 2010 proclaimed sanitation and access to potable drinking water as Human Rights. The World Toilet Day scheduled on 19th November, every year, reinforced the view of enhanced measures to access to proper sanitation[15].

The Indian scenario is no different from the world average in regard to sanitation. Concerted efforts were made from time to time in revamping sanitary practices. Millennium Development Goals (MDG) reiterated the idea of sanitation as one of the goals to be achieved before 2015. Total sanitation in India may be considered as an off shoot of MDG with a time frame of 2015. Eco-san toilets in this context assume importance[16]. Eco-san toilets in the Indian context is slowly gaining support in a few states and becoming lackluster in some states. There are a number of socio-economic and cultural reasons for this scenario. Human waste, both urine and faecal matter, on its own will not turn into manure automatically. What is required is composting materials which can remove pathogen from faeces and transform it into Bio manure[17,18].

Human waste compost used for this experiment work was obtained from the eco-san compost chambers constructed by Society for Community Organization and People's Education (SCOPE), Non Government Organization, Tiruchirappalli district, Tamil Nadu, India. Customarily, wood ash was used as composting material. Are there any other composting materials, besides wood ash, which could compost human faeces quicker with better recovery of nutrients? This was the precise research question that propelled us to conduct this experiment. Experiments were conducted to discern the differences in composting materials and its efficiency in recovering nutrients. Composting materials like wood ash, dry earth soil, saw husk and rice husk were employed in the study conducted by the authors. The experimental procedure is to spread the above materials on faecal matter for every defecation up to six months after sixth month the chamber was closed and allow it in this condition for six months towards composting. The purpose of the study is to find out the material which performs better than the other in reducing the time period of composting and nutrient recovery. The compost obtained from Eco-san compost chambers are odour less after six months and free from pathogens. Laboratory experiments have been carried out in three different places; Environmental Monitoring Service, Aurobrindavan, Auroville, Tamil Nadu, the Department of Environmental Management, Bharathidasan University, Tiruchirappalli, Tamil Nadu and the Department of Agriculture, Government of Tamil Nadu, Tiruchirappalli.

Eco-san Toilets: Dry latrine model is followed under Eco-san. Provision is made to segregate human excreta and urine at source level itself and collected at two separate chambers. Faeces are reserved to be disinfected by keeping it under dry condition inside the vaults. Eco-san panels are designed to have two separate holes on the highest point of every vault to receive faeces and landing up into the vault during defecation. For an average family size of 6 to 8 members, it takes six months to get the chamber filled. Another six months time is required for disinfecting and converting the faeces into organic manure (Figure-1, 2 and 3). All Eco-san users' urine collected in a urine tank by eco-san users first dilute urine with water in a ratio of 1:9 and then use in the agricultural field.

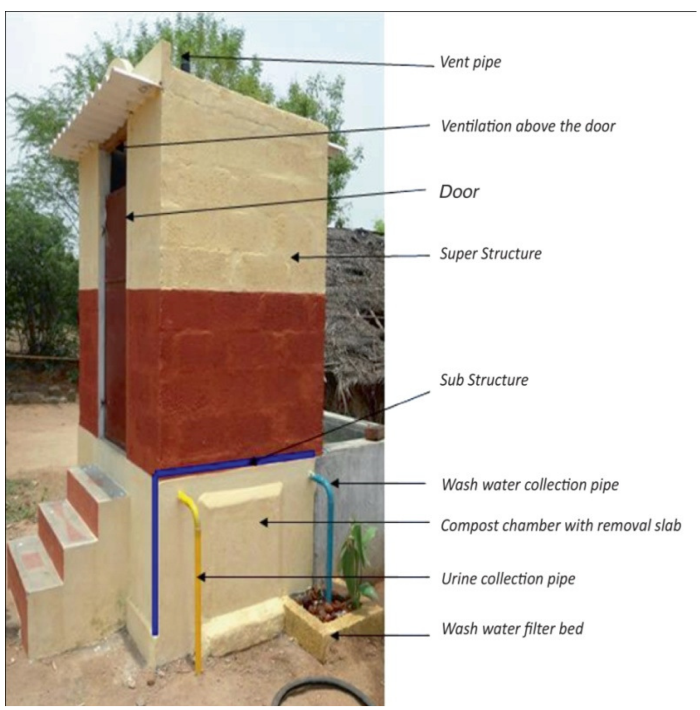

Figure-1: Outer structure of Eco-san Toilet.

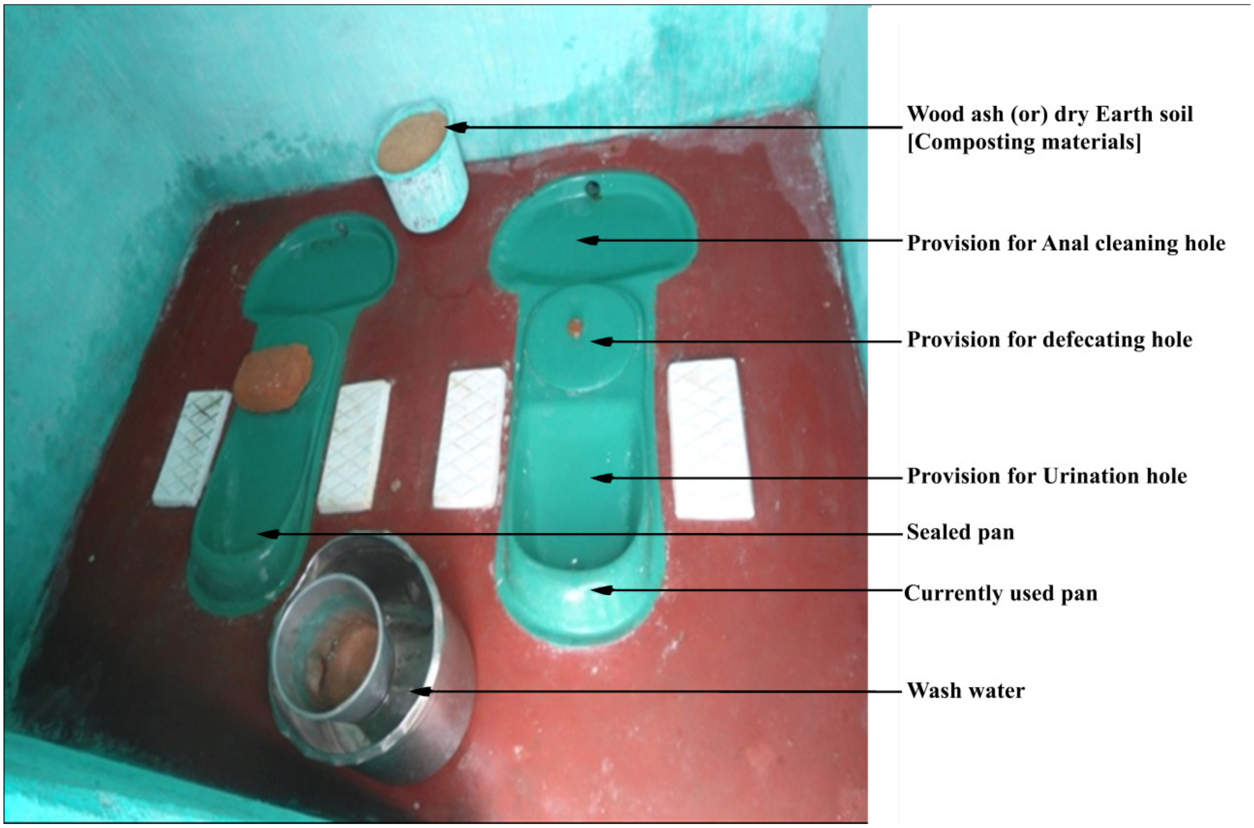

Figure-2: Inside view of Eco-san Toilet.

Figure-3: Recovery of compost manure.

The composition of the food intake determines the quantity of faeces excreted. Low fiber content food items like meat generated smaller quantity of faeces and vice versa. There is direct relationship between fiber content and faeces excretion: lower the fiber smaller the amount of faeces excretion and higher the fiber content greater the faecal generation. Developed countries recorded roughly 80-140 gram per day of faeces (wet weight), vis-à-vis of dry matter of about 25-40 grams per day[19-22]. Developing countries on the other recorded on average 350 gram per day in rural area as against 250 gram per day in urban areas[20]. It was 315 gram per day in China[23]. And in Kenya it was 520 grams per day[24]. Urine excretion is determined by intake of food, body exertion, temperature besides sweats[19,20]. For adults, the urine excretion ranged from 1000 to 1300 grams per day[20]. Urine generation recorded in Sweden was 1500 gram per litter[22] and it was 600-1200 gram per day in southern Thailand[25] and 637 gram per day on regular days of work and 922 grams per day on weekends in Switzerland[26]. Interestingly, an estimate by Austin L.M and Van Vuuren observed that "*the quantity of human waste of one individual in a year and the nutrients recycled thereof- is just equal to the fertilizer required to produce food grains per person per annum*[27]". Table-1 illustrates the potential value of excreta as a productive resource: An individual's average excreta per annum – just a half of one cubic meter of urine and 0.05 cubic meter of faeces, is sufficient to produce the quantity of fertilizer required to produce cereals for one individual (230 kilograms).

Material and methods

Different composting materials depending upon its availability in different regions may be considered for using as compost material. Now the question arises as to which composting material is more efficient in composting with less duration and recover nutrients from the human waste. Compost materials viz., saw husk, wood ash, dry earth soil and rice husk were taken for the experiment to understand the relative performance of the same.

Physicochemical analysis: A glass electrode pH 211 microprocessor pH-meter (Hanna Instruments) was used to measure the pH[28]. Organic matter content was determined by burning the dried sample at 550°C for 4 hrs[29]. By using a factor of 54 percent, the organic substance was transformed into carbon content[30]. Total Kjeldahl Nitrogen (TKN) was determined by the semi-micro-Kjeldahl method[29]. Various elements including Phosphorous, potassium and other elements of the samples were analyzed according to the USEPA 2008[31]. Aqua regia digestion was adopted to estimate the total metal content. Briefly, one gram of human waste compost from each sample was digested with aqua regia (HNO_3/ HCl = 1: 3) and $HClO_4$ for two hours to determine the concentrations of Fe, Mn, Cu, Cr, Pb, Zn and Ni[32].

Biological Analysis: The human waste compost sample was tested using prescribed media for the presence of pathogens like *E.coli* and *Salmonella*. The procedure followed was to take a gram of compost sample in water blank and to mix it thoroughly. The solution was shacked for 15 minutes to ensure complete dispersion (10^{-2} dilution). The obtained solution was further diluted by transferring the solution in to a 9 ml water blank, thereby ensuring 10^{-3} dilution. The presence of pathogens gets reduced in a sample when serially the dilution process was carried out thereby scaling to 10^{-4} and 10^{-5}dilution level. 1 ml samples of the solution at 10^{-4} and 10^{-5} dilution was transferred to petridishes. The media suitable for conducting the test should be melted and cooled, just near to solidification state and 15 ml of media was poured in to petridish containing 1 ml diluted sample solution. The sample solution and media were mixed and stirred for 3 to 4 times in both clock wise and anti-clock wise direction. The plates in the reversed (upside down) position were incubated under room temperature for 2 to 3 days. After two days the plates were observed for the *E.coli* and *Salmonella*[33].

Statistical analysis: The Statistical Package for Social Sciences, (SPSS 16.0), computer software package. Univariate ANOVA was used to Analysis of Variance (ANOVA) was applied to understand the difference between composting materials and months. A Duncan t-test was also performed in finding out the similar type of data sets of among different composed materials for different months of human waste in ecological sanitation experiments.

Table-1: Nutrients from human waste and the amount of fertilizer needed to produce Cereal per annum.

Fertilizer	500 liters Urine	50 Liters faeces	Total Excreta	Fertilizer needed for 230 kg of cereal
Nitrogen	5.6 kg	0.009 kg	5.7 kg	5.6 kg
Phosphorous	0.4 kg	0.19 kg	0.6 kg	0.7 kg
Potassium	1.0 kg	0.17 kg	1.2 kg	1.2 kg
Total (N+P+K)	7.0 kg (94%)	0.45 kg (6%)	7.5 kg (100%)	7.5 kg (100%)

Source: Wolgast (1993), quoted in Austin & Van Vuuren (2001)[27].

Results and discussion

Results obtained from the three different labs are consolidated, presented from Figure-4 to 12 and in Table-3. In general, moisture content in the compost is related to the amount of bulking materials that are added in addition to the faecal matter. The moisture content in compost material was observed in decreasing trend throughout the experimental period. However, in certain bulking material combination (wood ash and dry earth) the reduction level varied between low to moderate (Figure-4) (25 to 60 percent). The slow reduction was due to the fact that lechate was not allowed to leave the composting reactor and the reactors were maintained at controlled temperature and humidity[34]. Moisture enables organism survival both in soil and faeces. A moist soil favours the survival of microorganism and the drying process will induce reduction of number of pathogens[35].

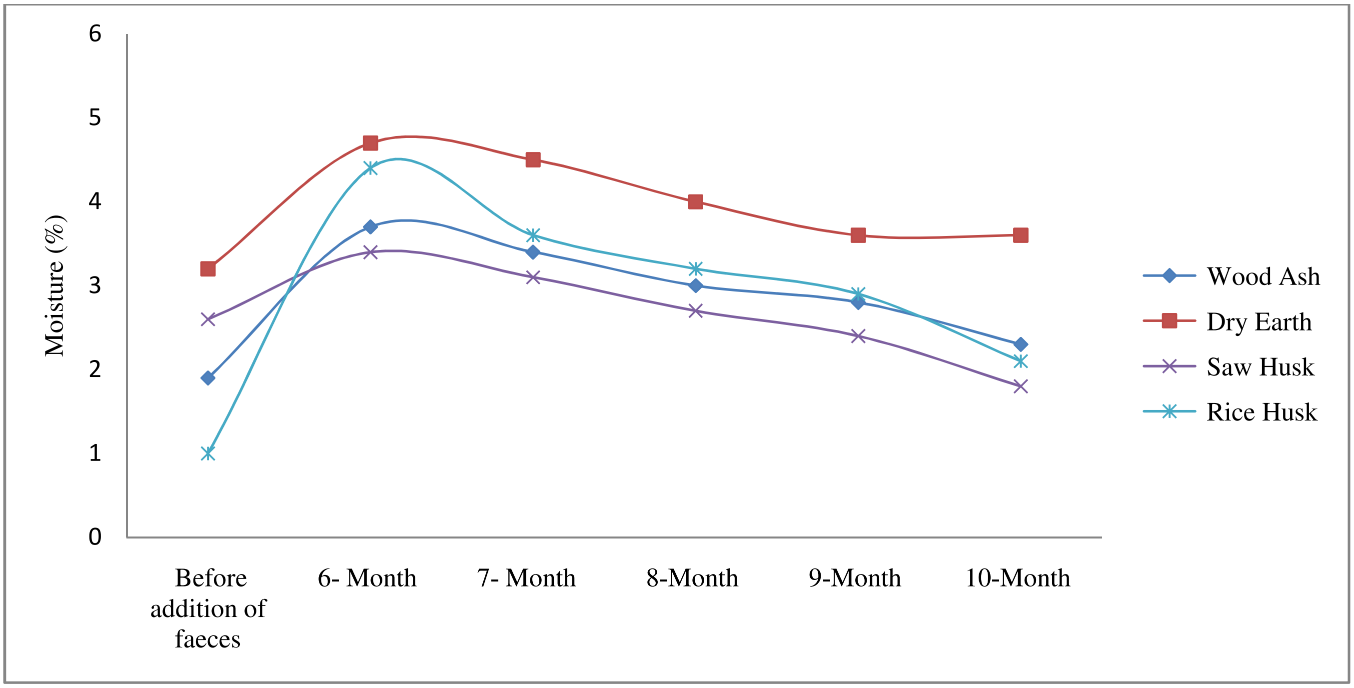

Figure-4: Moisture – Data measured during composting experiments with excreta.

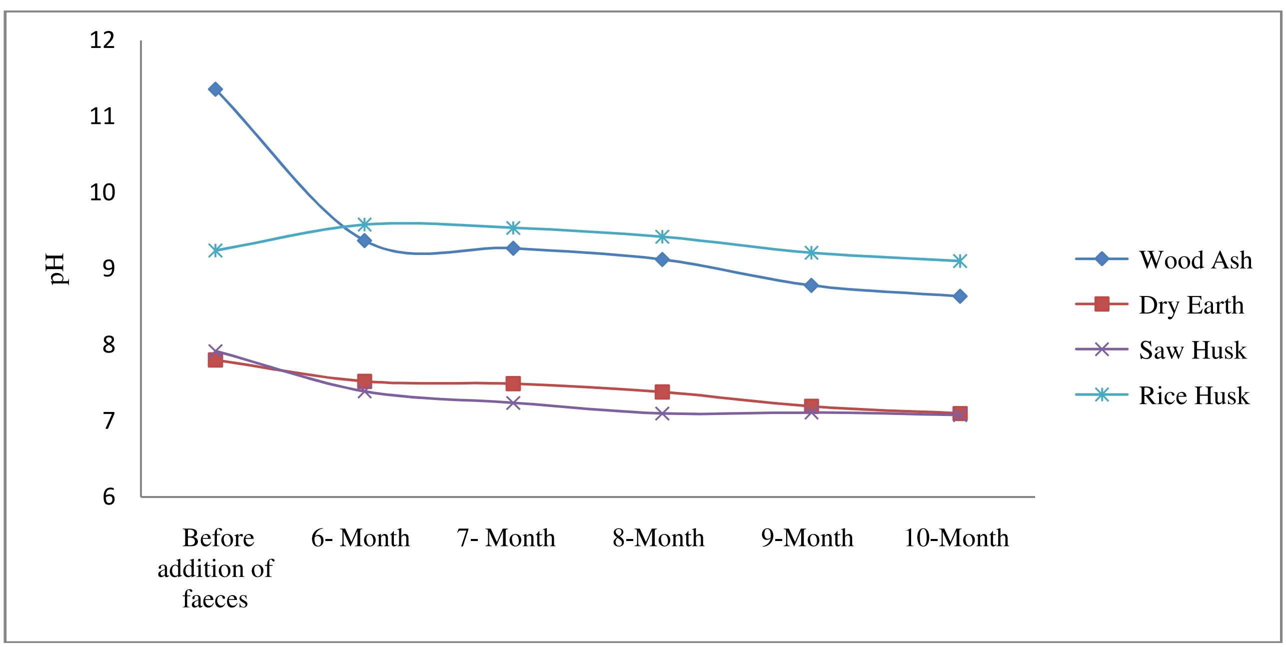

Figure-5: pH – Data measured during composting experiments with excreta.

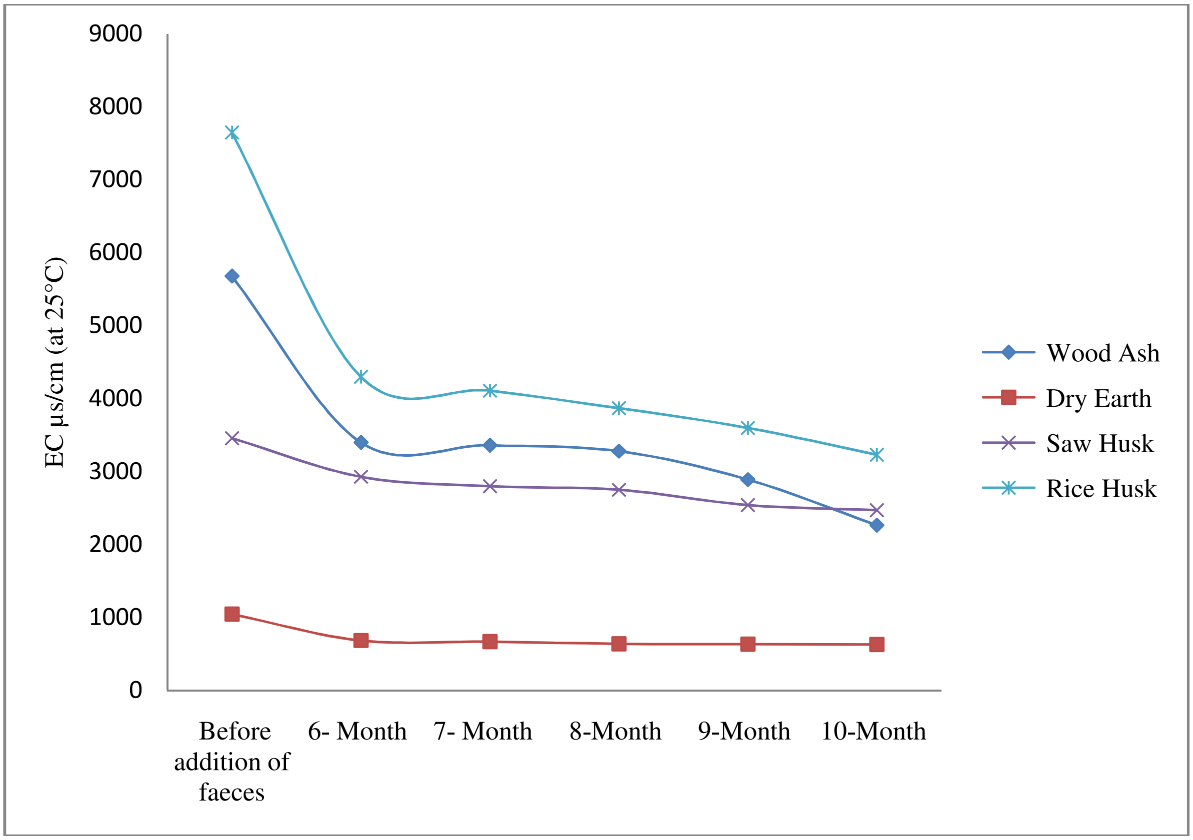

Figure-6: EC- Data measured during composting experiments with excreta.

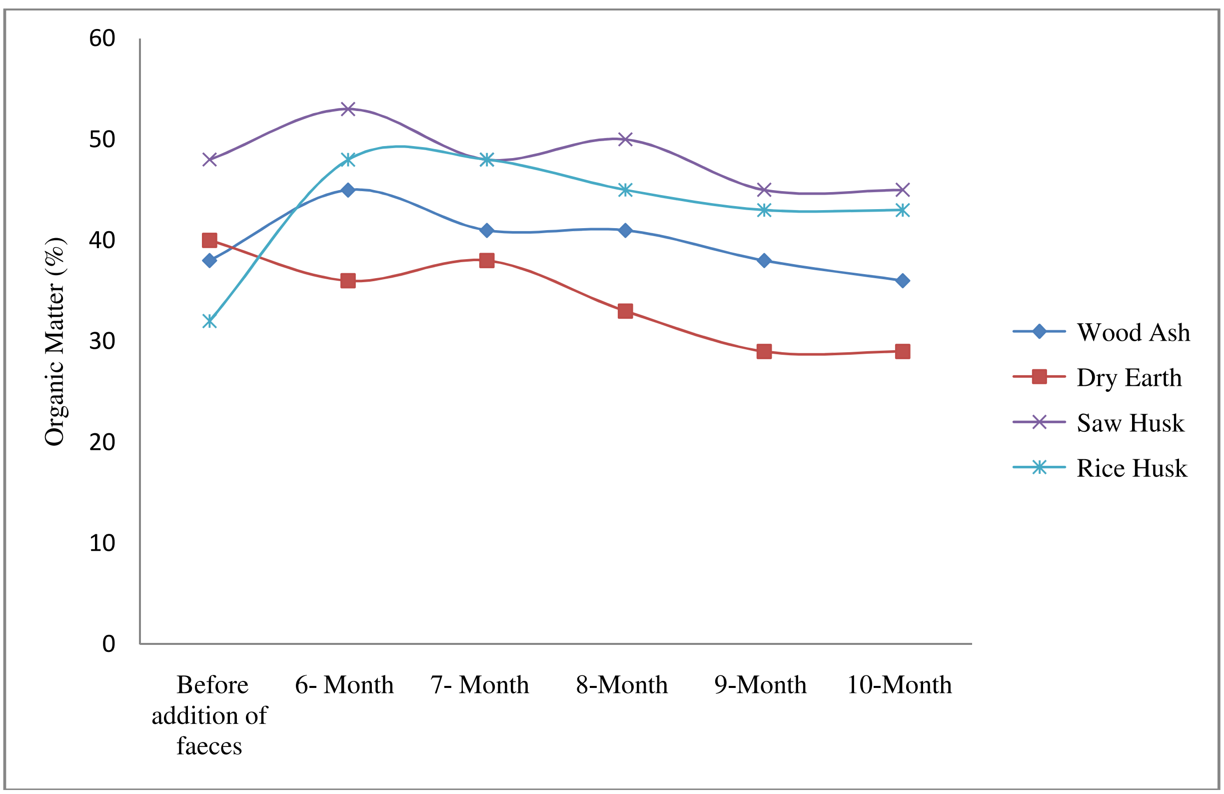

Figure-7: Organic Matter - Data measured during composting experiments with excreta.

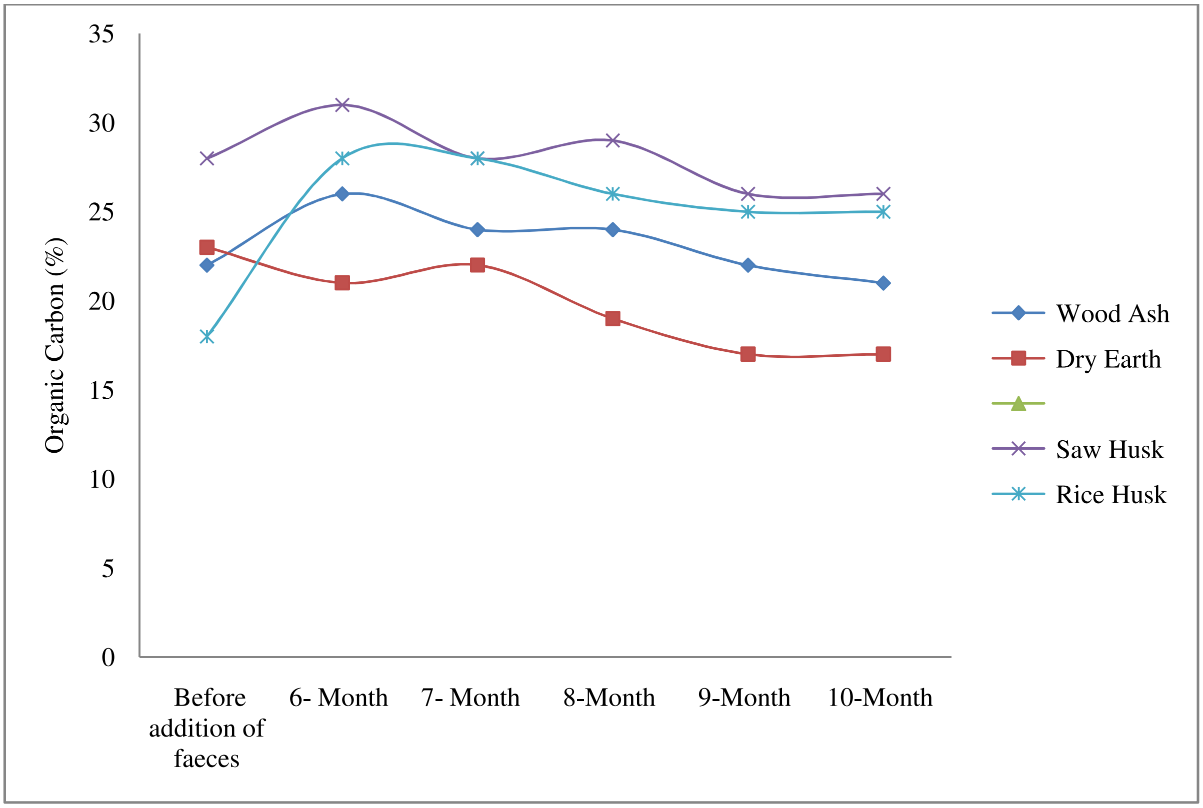

Figure-8: Organic Carbon - Data measured during composting experiments with excreta.

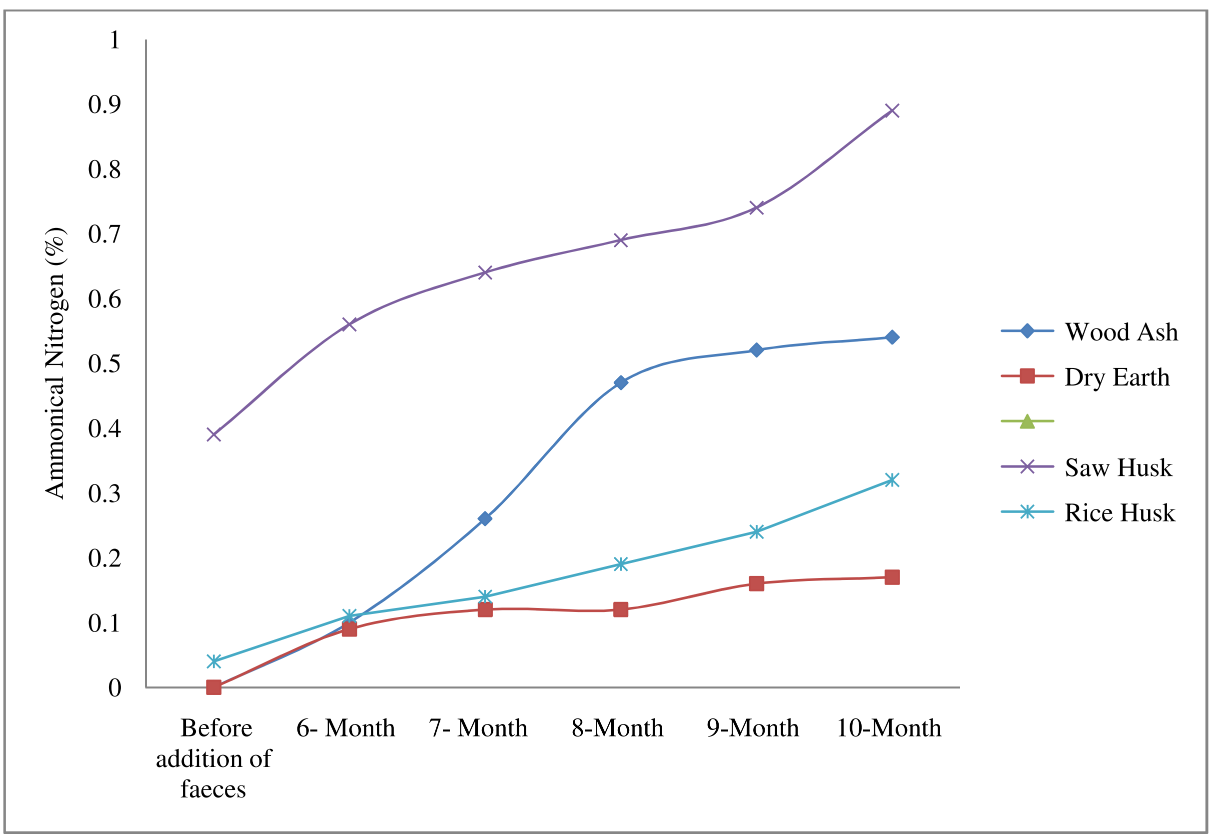

Figure-9: Ammonical Nitrogen - Data measured during composting experiments with excreta.

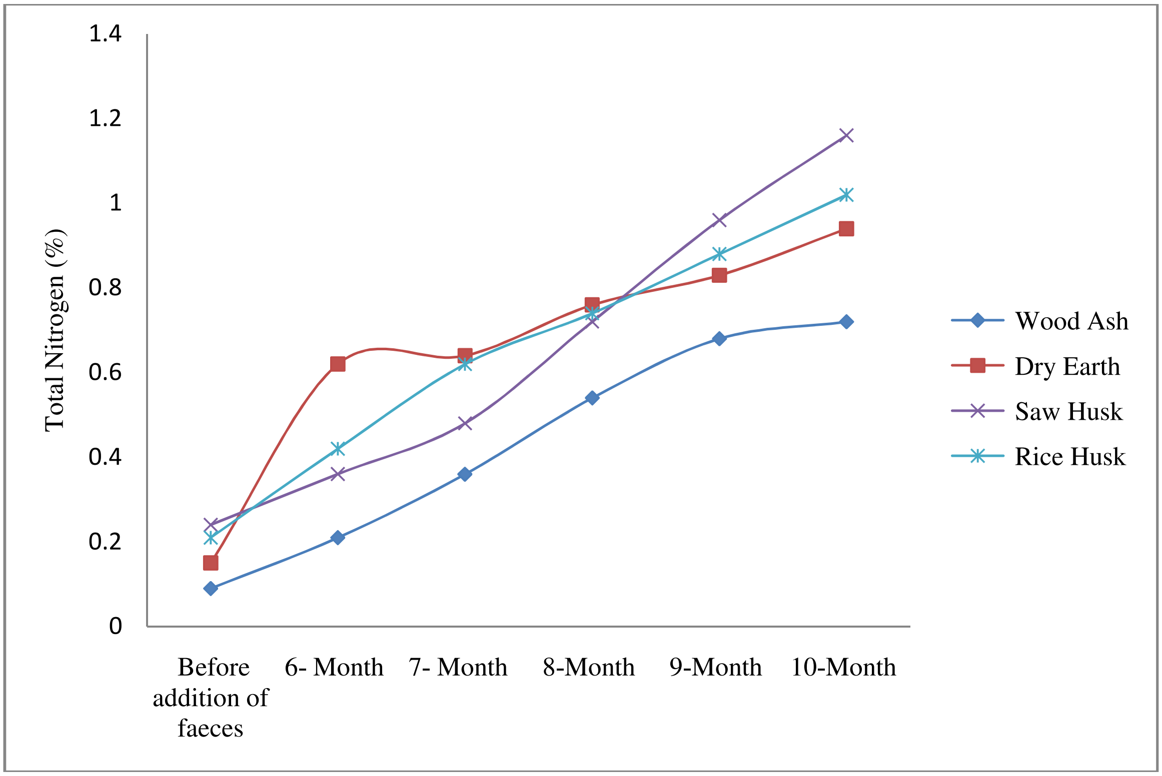

Figure-10: Total Nitrogen - Data measured during composting experiments with excreta.

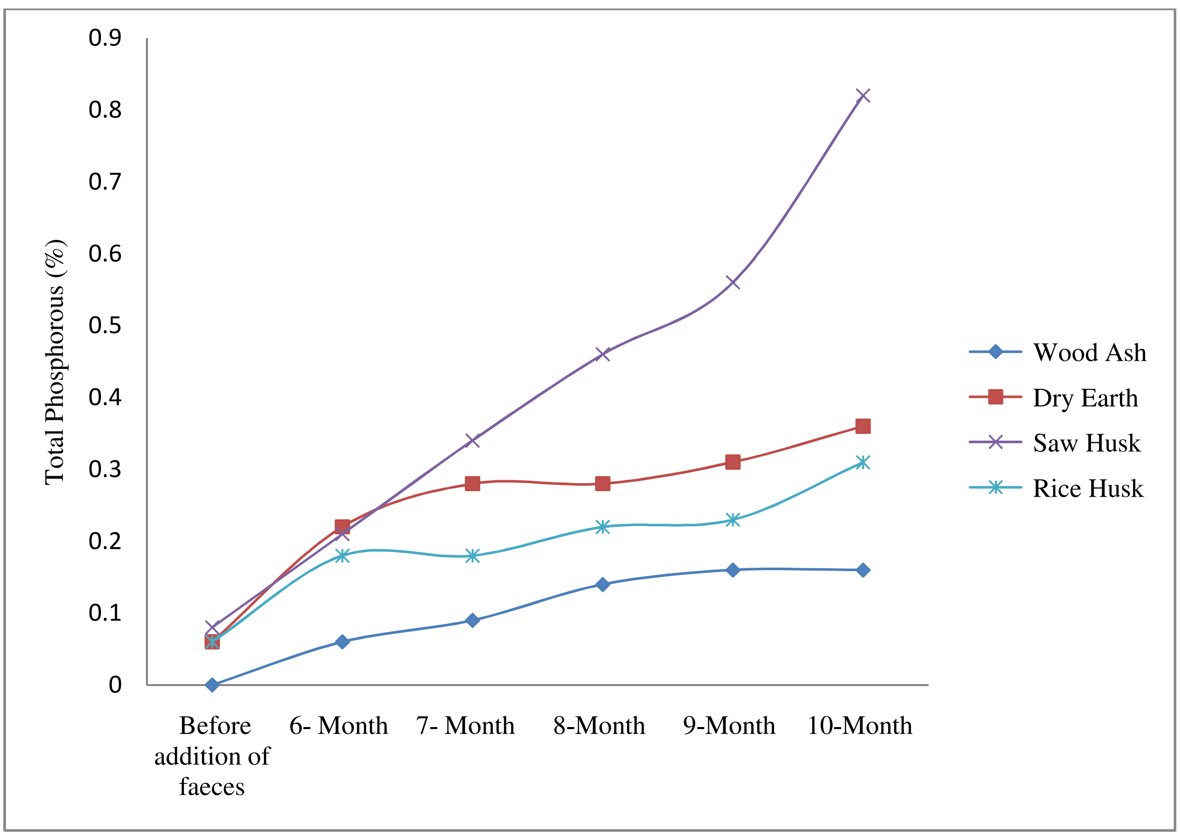

Figure-11: Total Phosphorous - Data measured during composting experiments with excreta

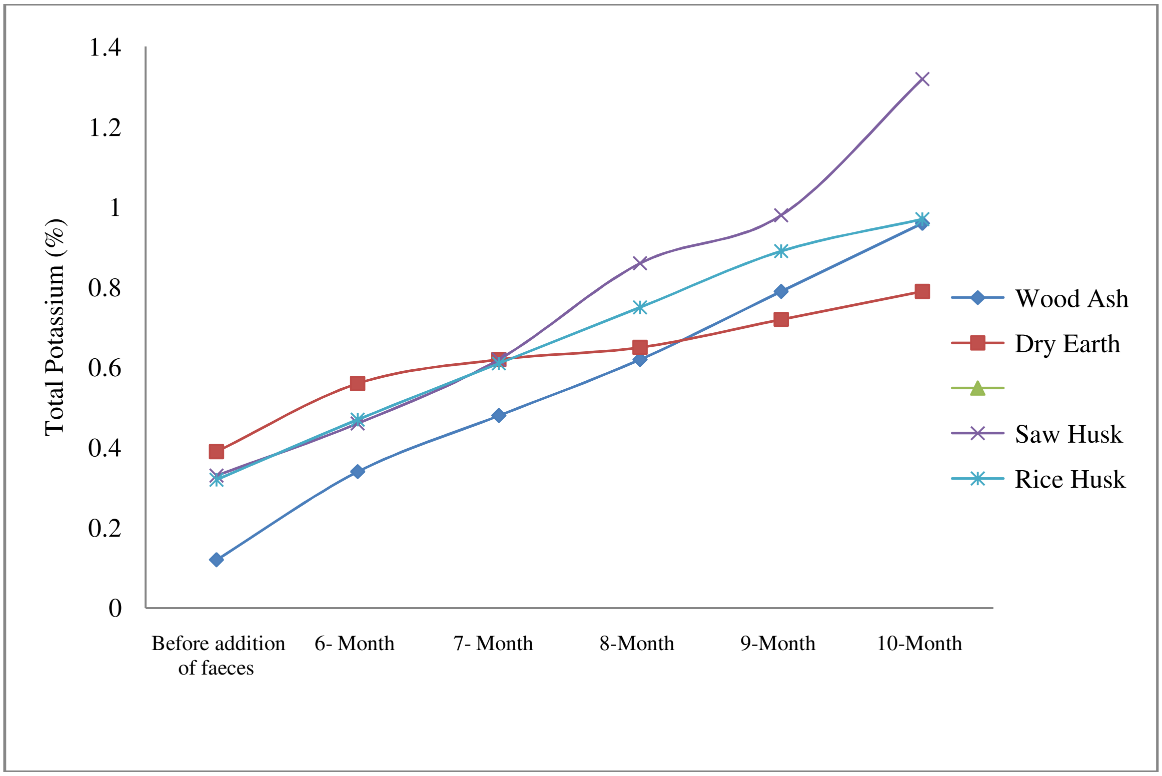

Figure-12: Total Potassium - Data measured during composting experiments with excreta.

The pH of the sixth and tenth month compost varied in the range of 7.52 - 9.58 and 7.08 - 9.10, respectively (Figure-5). Essentially, pH at 11-12 would infact facilitate killing disease causing pathogens, while pH of 7-8 could suit more as compost. Throughout the composting process pH level varies from alkaline to near neutral. Significant changes in the pH may be due to decomposition of organic matter present in faecal matter and bulk materials (saw dust, rice husk, dry earth soil and wood ash) followed by organic acid formation. Some of the earlier studies also highlighted the changes in pH of compost in relation to degradation of organics and formation of intermediate products such as ammonium ions and humic acids[36-38]. Adaptation of microorganism to neutral pH is common, but highly acidic or alkaline conditions will lead to negative effect. The significant reduction in electrical conductivity (EC) was noted throughout the composting process of all bulking material (Figure-6) combinations may be attributed to precipitation of soluble salts and the volatilization of ammonia due to the generally high pH values of bulking materials[39].

All the bulking materials also significantly contribute in organic matter content in addition to the faecal matter which is known for higher proportion of organic matter (Figure-7). Organic carbon content in sixth and tenth month compost was measured in the order; Rice husk > Saw husk > Wood ash > Dry earth soil and Saw husk > Wood ash > Dry earth soil respectively (Figure-8). The study conducted by Hotta and Funamizu[40] reported about 85 percent of initial faecal carbon was biodegradable in the composting process whereas Lopez et al.[41] had reported that its biodegradability was 80 percent.

Ammonical nitrogen level in compost materials varied in the range between 0.17 and 0.89 percent. Maximum level was recorded in Saw husk combination whereas minimum was noted in dry soil combination (Figure-9). The major nutrients (NPK) concentration was found to be low in the initial period of composting but eventually ended up with notably higher concentrations. Concentration of total nitrogen, total phosphorous and total potassium was measured in the range of 0.21 - 1.16, 0.012 - 0.82 and 0.003 - 1.32 percent, respectively (Figure 10-12). Earlier studies conducted by numerous researcher documented notable reduction in the major nutrients level throughout composting process. Notwithstanding the fact that earlier studies were performed in open roof devoid of forming any layering on soil surface which are familiar for nutrient loss in terms of volatilization and leaching losses. In contrast, the present study reveals higher concentration of major nutrients at the end of composting period. This increasing trend of major nutrients in compost probably because of trace or nil level of leaching loss and in-vessel composting process which are characterized by no volatile loss of nutrients[42].

It is known that basic soil nutrients like nitrogen, phosphorous and potassium are inevitable for agricultural crop production. Requirement of phosphorous is greater in agriculture the nutrient, which is easily a mined one, has little or no heavy metal. Supply of phosphorous from rocks would not prolong for more than one century[43-45]. The limited phosphorus resources are calling attention to the critical need to close the nutrient cycle loop in sanitation[46]. It is relevant to state have that conserving of phosphorus from urine and feces can meet out about of 22 percent of the phosphorus demand. According to Mihelcic et al., the availability phosphorous from human faeces was estimated to go up from 3.36 to 1.33 million metric tons by 2050[46].

Human excreta subsumes nitrogen and phosphorous which are essential for plant growth of the 3-3.33 million metric tons of phosphorous found in human excreta and gray water, an estimated 0.3-1.5 million metric tons of phosphorous per annum used again[44,46,47]. It is interesting to note the observation made by Mihelcic et al. regarding the efficiency of recovery and reuse of nutrients in region with low sanitation coverage vis-à-vis high sanitation coverage[46]. Low sanitation coverage region registered better recovery and reuse of nutrients while the high sanitation coverage lagged behind in this respect for want of huge investment. Food consumption determines the nutrient content of faeces primarily depends upon food consumption. Food nutrients content as a proportion of faecal matter revealed the following 10-20 percent nitrogen (N), 20-50 percent phosphorus (P) and 10- 20 percent potassium (K)[19,22,48,49].

According to Esrey et al., the prescribed Carbon and Nitrogen (C:N) ratio for composting toilets ranged between 15:1 and 30:1[50]. In the present study, C:N ratio of tenth month compost was recorded in the range from 18:1 and 29:1. Maximum and minimum level of C:N ratio was recorded in wood ash and dry earth soil combination with faecal matter, respectively. A substantial fall in C:N was noted during the tenth month compost as compared to the sixth month compost.

The outcome of the experiment at the end of tenth month where the measure of heavy metal concentration showed as; Fe > Zn > Cu > Cr > Ni > Pb > Cd (Table-2). In terms of analysed heavy metals, the sequence of concentration as follows, Dry earth > Saw husk > Rice husk > Wood ash. Another research work by Vinnerås et al. reported the presence of heavy metal in human faeces[22]. It included Zn, Cu, Ni, Cr, Pb, Cd and Hg with concentration as 11, 1.1, 0.07, 0.02, 0.02, 0.01 and 0.01 mg as per person per day. Evidences suggest that urine and faeces carry lower concentrations of heavy metals when compared to farmyard manure[21]. However plants do require trace or micronutrient elements such as Na, Zn, Cu, Fe and Mn, in a little concentration for proper growth and reproduction[51].

However skeptics argued that human faecal matter, even after composting, may not suit as fertilizer because of microbial risk like hookworm infection[52], organic and inorganic pollutants[53,54]. Studied faecal pathogens (*E.coli* and *salmonella)* are totally absent throughout the composting process. *E.coli* and *Salmonella* are absent because of alkaline condition. Earlier study conducted by Sossou et al. has found emergence of *Enterococci* in composting toilet[55]. Increased level of dry bulking materials brought down the moisture content to reduced levels that approve composting microorganism[56]. Among the materials studied, dry soil combination stands as one among the suitable material in terms of organic matter decomposition and nutrient recycling process. Since, soil is known for high microbial diversity in nature it ultimately intensifies composting process[57].

Table-2: Heavy metal concentration in ten month eco-san toilet compost with various bulking materials combinations. (Dry weight basics, mg/kg).

Metals	Wood Ash	Dry Earth	Saw Husk	Rice Husk	Maximum permissible limit as per Indian compost standard (2013)	Detection Limit (µg/L)
Fe	3934	4580	4210	4082	NA	0.02
Cu	4.30	10.20	3.40	8.60	300	0.02
Cr	0.96	3.60	2.20	1.55	50	0.01
Zn	130	230	152	115	1000	0.001
Pb	0.72	0.81	0.22	0.41	100	0.05
Ni	0.92	1.60	0.70	0.95	50	0.2
Cd	0.06	0.02	0.05	0.13	5	0.003
As	BDL	BDL	BDL	BDL	10	0.2
Hg	BDL	BDL	BDL	BDL	0.15	2

NA - Not Applicable, *BDL – below detectable limit.

Table-3: ANOVA Result – Differences among composting materials and composting months.

Parameters	Significant compost materials				Significant Composting Months			
	Materials	Mean Value	F-ratio	Rank	Month	Mean Value	F-ratio	Rank
Moisture$^{@}$	Saw husk Wood ash	2.67 2.85	10.65^{***}	1 2	Control 10^{th}	2.17 2.44	16.00^{***}	1 2
pH	Saw husk Dry earth soil	7.306 7.411	17.70^{***}	1 2	10^{th} 9^{th}	7.99 8.08	NS	1 2
Ec$^{@}$	Dry earth soil Saw husk	718.20 2825.0	50.30^{***}	1 2	10^{th} 9^{th}	2149 2421	3.36^{***}	1 2
Organic$^{@}$ Matter	Dry earth soil Wood Ash	33.89 39.45	33.48^{***}	1 2	10^{th} 9^{th}	37.58 38.58	2.83^{**}	1 2
Organic$^{@}$ Carbon	Dry earth soil Wood Ash	19.33 22,94	30.69^{***}	1 2	10^{th} Control	21.58 22.25	2.59^{**}	1 2
Ammonia Nitrogen$^{@}$	Saw husk Wood Ash	0.645 0.311	49.94^{***}	1 2	10^{th} 9^{th}	0.48 0.41	4.42^{***}	1 2
Total Nitrogen$^{@}$	Dry earth soil Saw husk	0.656 0.653	2.58^{*}	1 2	10^{th} 9^{th}	0.96 0.84	73.00^{***}	1 2
Total Phosphorous$^{@}$	Saw husk Dry earth soil	0.41 0.25	15.01^{***}	1 2	10^{th} 9^{th}	0.41 0.31	9.04^{***}	1 2
Total Potassium$^{@}$	Saw husk Rice husk	0.76 0.66	2.00 NS	1 2	10^{th} 9^{th}	1.01 0.84	57.41^{***}	1 2
E.coli$^{@}$	Dry earth soil Rice husk	0.00 0.00	19.85^{***}	1 2	Control 10^{th}	14.00 18.75	2.062^{*}	1 2
Salmonella	-	-	-		-	-	-	

*** 1%, ** 5 % and *10 % level of significance. @ Interactive effect by material and composted month. NS – Non Significant.

ANOVA results (Table-3) confirm that the mean value of all the tested parameters turned out to be significant with different composting material (namely dry earth soil, saw husk, rice husk and wood ash) and composting months (1 to 10 months). Duncan test is employed to understand the extant of mean variation among the composting material and composting months. Out of four, dry earth soil come out significant as foremost material against Ec, Organic Matter, Organic Carbon, Total Nitrogen and *E.coli*. The Dry earth soil is significant second foremost material show the mean variation pH, and Total Phosphorous. In regard to crucial nutrient recovery of NPK, saw husk proved better followed by dry earth soil as the best among the four variables as even *E.coli* is absent in dry earth soil, while it is present in saw husk for few months. All the composting materials under experiment showed that only after 9^{th} and 10^{th} month they became suitable for land application. On completion of six months, the chosen composting materials were considered for the experiment.

Conclusion

Eco-san toilets may help achieve win-win situation by means of converting human waste into bio manure on the one hand and be a deterrent to open defecation. Access to locally available composting materials is one of the bottlenecks of use of eco-san toilets. The authors made laboratory experiments to assess the relative efficiency of four different composting materials. Carbon-Nitrogen (C, N) ratio of 20:1 is an ideal proportion for good composting. The experiments conducted by the authors ascertained that C:N ratio of tenth month compost was recorded as 18:1 for dry earth soil combination with faecal matter. Heavy metal analysis brought forth the fact that on completion of tenth month composting, the concentration measured as Fe > Zn > Cu > Cr > Ni > Pb > Cd across dry earth soil > saw husk > rice husk > wood ash >, respectively. The silver lining of dry earth soil as compost material is, that it is completely free from microbial population from the sixth month to tenth month of composting period. Besides, the ANOVA results confirmed that dry earth soil as composting material is best suitable after nine months of composting period. The upshot is of the four composting materials studied-dry earth soil combination turned out to be a suitable material with respect to organic matter decomposition and nutrient recovery.

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