EFFECT OF BIODIGESTER COLOUR AND MANURE TYPE ON BIOGAS PRODUCTION

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ABSTRACT

Four plastic biodigesters with blue, yellow, black and white colours were used to carry out anaerobic digestion of three wastes, namely, cow dung, poultry manure and swine manure, in a 3 × 4 factorial experiment laid out in a randomized complete block design with the aim of studying the effect on biogas production. Substrate temperature, pH and biogas yields were monitored during the 63-day study. The results showed that both biodigester colour and manure type had significant ($p \leq 0.05$) effect on biogas yield. Biogas yield (dm^3 kg^{-1} VS fed day^{-1}) was highest in poultry manure (57.9) followed by swine manure (27.3) and cow dung (6.85). The bio-digesters had biogas yields in the order: black (34.2)>blue (32.5)>yellow (29.5)>white (26.5). However, the blue biodigester was equally ($p > 0.05$) as effective as the black biodigester in biogas production. Poultry manure in the black digester had the highest biogas production. In terms of stability of biogas production, the blue digester performed best compared to the other biodigesters based on the least number of non-production days. Considering the biogas yield and stability of production, it was concluded that poultry manure had the highest biogas yield while blue biodigester is suitable for enhancing sustainable biogas production.

Keywords: Anaerobic digestion, bio-digester colour, manure, biogas yield

INTRODUCTION

Anaerobic digestion (AD) technology is increasingly important for waste management as it generates renewable energy from organic wastes in an environmentally benign way. The renewable energy in form of biogas can be used for diverse purposes as cooking, lighting and powering internal combustion engines (Agunwamba, 2001; Mashandete and Parawira, 2009). Several factors have been reported to affect the reaction process which leads to the ultimate formation of biogas. These factors include feedstock materials, temperature, carbon (C) to nitrogen (N) ratio, pH and buffering capacity, co-digestion, pre-treatments and additives, mixing and reactor design (Ezekoye and Okeke, 2006; Ward *et al*., 2008; Iyagba *et al*., 2009).

AD feedstocks are organic material which can be plant or animal based. Animal manures have high degree of biodigestibility (Odeyemi, 1982) and biogas yield, which have made them widely used materials for AD.

In a subtropical country like Nigeria, the prevailing ambient temperatures are within the mesophilic range (25-42^{0}C); hence, anaerobic digestion/biogas production takes place mostly at these temperatures. Due to the significance of colour on heat absorptivity/emissivity of materials and the effect of heat on anaerobic digestion, colours of biodigester materials have become an overriding factor in biogas production. Different wavelengths (colours) of light have different amounts of energy. For instance, a black object (emissivity ≈1) absorbs all wavelengths of light and converts them into heat so that the object gets warm. A white object (emissivity ≈0) reflects all wavelengths of light, so the light is not converted into heat and the temperature of the object does not increase noticeably. All other colours fall in between white and black in terms of absorptivity/emissivity (Fidali and Mikulski, 2008). Plastic biodigesters are increasingly gaining prominence because they are lightweight, relatively more durable, re-fabricable, resistant to corrosion in a liquid environment and strong enough to withstand operating temperatures at prolonged exposure to sunlight (Kumar and Bai, 2005). However, most plastic biodigesters are drums adapted and not originally designed for anaerobic digestion. Plastic drums are manufactured in different colours mostly black, white, yellow, blue, green and brown. While it is obvious that a black digester will likely produce higher biogas yield, the effect of other colours especially yellow and blue on anaerobic digestion is not well understood. This study, therefore, sought to evaluate the performance of plastic biodigesters with different colours and determine the effect of manure types (MT) on anaerobic digestion and biogas production.

MATERIALS AND METHODS

The experiment was conducted at the Department of Agricultural and Environmental Engineering, Obafemi Awolowo University, Ile-Ife, Nigeria. It was a 3 × 4 factorial experiment laid out in a randomized complete block design to assess the effects of biodigester colour (blue, yellow, black and white) on biogas production from three manure type [cow dung (CD), poultry manure (PM) and swine manure (SM)]. Fresh poultry and swine manures and cow dung were collected from the Obafemi Awolowo University Teaching and Research Farm. The plastic containers adapted as biodigesters were purchased from a plastic merchant in Ile-Ife town.

Samples were analysed for Total Solids (TS) (oven dried at 105^{o}C for 24 h); Volatile Solids (VS) (ashing of TS at 550^{o}C for 5 h); Total Nitrogen (TN) (Kjeldahl method; Bremner, 1996); pH (1:10 w/v sample:water extract, using a digital pH meter). The Total Carbon (TC) content was estimated from the ash content according to the formula developed by Mercer and Rose (1968):

$$TC\,(\%) = [100 - Ash\,(\%)]/1.8$$

The experimental set up comprised of biodigesters, water tanks and water collectors. The biodigesters were adapted using cube-shaped 25 dm^3 plastic kegs and were positioned to give 2.50 × 4.65 dm^2 surface and 2.15 dm height dimensions. A drain plug was fitted at the base of each biodigester for collection of samples for pH determination. Each biodigester had a digital thermometer probe fitted to it for temperature measurement. Similarly, the water tanks and water collectors were adapted using cube-shaped 10 dm^3 and 5 dm^3 plastic kegs, respectively. Rubber hose was used to connect each biodigester to the water tank and the water tank to the water collector.

After the moisture content determination, each manure was diluted with clean tap water to 8% TS, as recommended by Zennaki *et al*. (1996), agitated vigorously and poured through a 6 mm plastic mesh to remove gross solids. The biodigesters were loaded once during the experiment to 70% of their capacities. Each treatment was replicated thrice with two placed outdoor under direct sunlight and one placed indoor in the laboratory. The biogas produced was collected by water displacement method (Archimedes' principle) and measured using a calibrated cylinder (Itodo *et al*., 1992). The biodigesters were manually agitated once daily to avoid long period of settlement of the substrates and ensure uniform distribution of microorganisms and heat within the substrates. Ambient and substrate temperatures and biogas yields were measured daily while substrate pH was measured weekly.

Data generated were subjected to two-way analysis of variance (ANOVA) using the Statistical Analysis Systems software (SAS, 2002) to compare variations in substrate temperature and substrate pH, and biogas yield. Where significance was indicated at $p \leq 0.05$, Duncan's Multiple Range Test was used to separate the means.

RESULTS AND DISCUSSION

The initial C:N ratios of poultry PM and SM (Table 1) were within the ratios recommended for stable biological degradation (Kayhanian and Hardy, 1994) and the sustainability of organic substrates for methanogenesis (TERI, 1985). Cow dung had the highest initial C:N ratio and pH. The experiment was terminated at 63 days where most treatments had ceased biogas production.

Table 1 - Initial properties of the manure types

Manure Type	Properties (dry weight basis)				
	pH	VS (%)	TC (%)	TN (%)	C:N ratio
Cow dung	7.8	95.688	53.16	1.15	46.2
Poultry manure	6.8	61.092	33.94	1.23	27.6
Swine manure	6.7	92.124	51.18	1.96	26.4

VS: volatile solids, TC: total carbon, TN: total nitrogen

Substrate temperature

The results showed that neither biodigester colour (DCo) nor manure type (MT) affected (p > 0.05) temperature of the treatments (Table 2). The ambient temperatures during digestion were between 21 and 32.5°C during the night and afternoon, respectively. The substrate temperatures fluctuated within the mesophilic range of 25-42 °C considered optimal for the support of biological reactions (Tchobanoglous *et al*., 2003). The daily temperatures recorded were averaged weekly and the profiles are shown in Figure. 1. The profiles followed the same pattern in all the treatments. The temperatures increased gradually from the initial of about 26°C in all the treatments to between 28.3 and 31.4°C by week 2 after which there were slight declines by week 3. The other weeks had slightly higher temperatures, indicating increased microbial activities during the process of digestion. Cow dung treatments had low and close temperatures during digestion. Poultry manure substrate in the yellow biodigester had temperatures close to ambient values during digestion.

Table 2 - ANOVA table showing the effects of digester colour and manure type on measured parameters

Parameter	Source	Df	SS	MS	*F*-value	Pr>F
Temperature	DCo	3	5.598	1.866	0.24	0.870
	MT	2	5.947	2.973	0.38	0.690
	DCo*MT	6	18.754	3.126	0.40	0.874
	Error	24	188.980	7.874		
pH	DCo	3	0.005	0.002	0.03	0.993
	MT	2	0.799	0.399	77.44	<0.001
	DCo*MT	6	0.037	0.006	1.20	0.342
	Error	24	0.124	0.005		
Biogas	DCo	3	312.356	104.118	5.69	0.004
	MT	2	15818.316	7909.158	431.99	<0.001
	DCo*MT	6	198.481	33.080	1.81	0.140
	Error	24	439.408	18.309		

DCo: digester colour, MT: manure type, Df: degrees of freedom, SS: sum of squares, MS: mean of squares

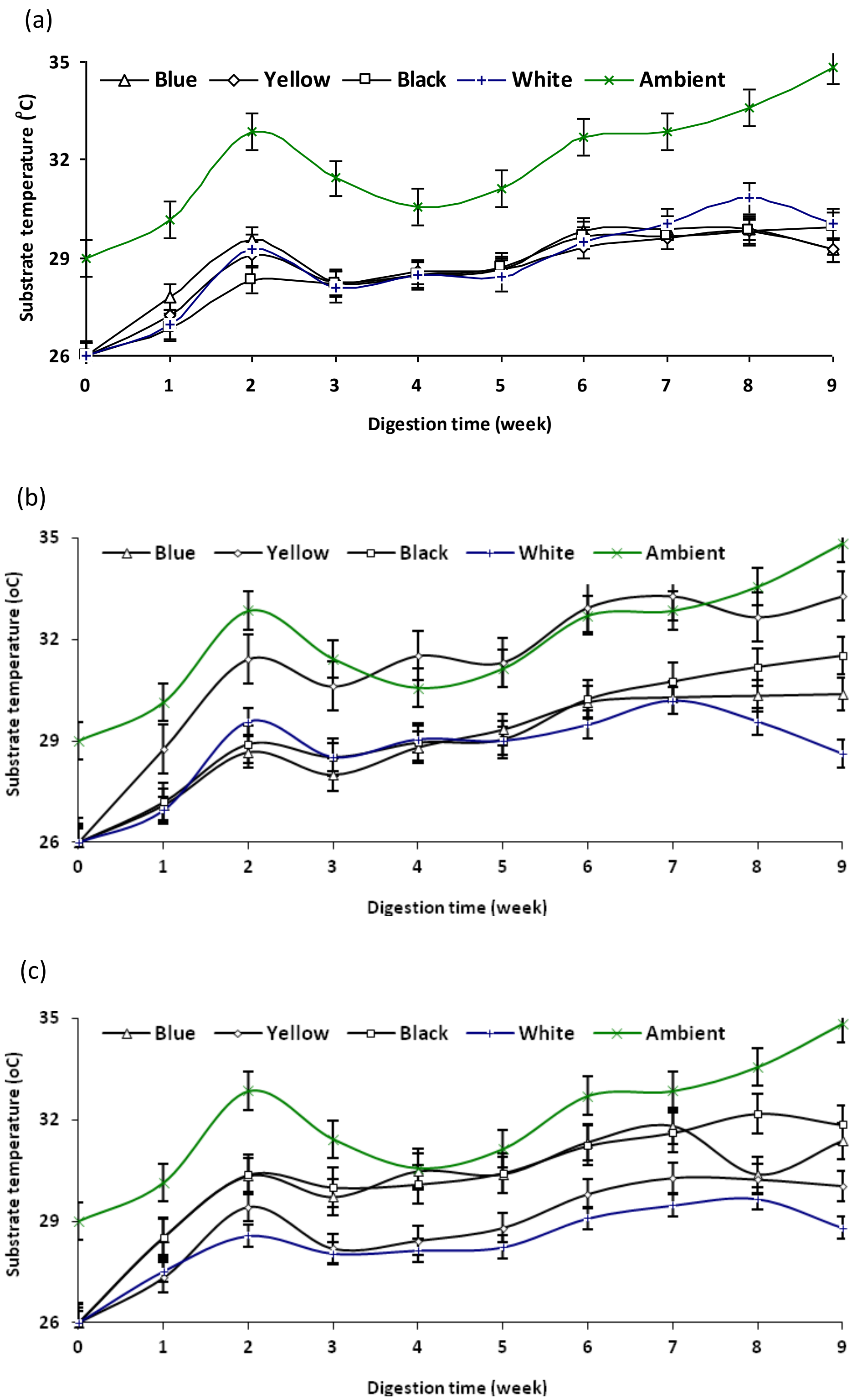


Figure 1. Profile of weekly temperature during digestion in (a) Cow dung, (b) Poultry manure and (c) Swine manure.

Substrate pH

The pH values during digestion indicated that the media were conducive for biogas production. They ranged from initial values of 6.7-7.8 to final values of between 6.8 and 7.6 (Fig. 2), suggesting that souring did not occur during digestion. It was observed that DCo did not affect ($p > 0.05$) the pH but MT did ($p \leq 0.05$) (Table 2). The poultry manure substrate had the highest average pH during digestion while SM had the least (Table 3). The pH profiles for the three substrates (MT) followed the same pattern. In CD treatments (Fig. 2a), the pH decreased from the initial value of 7.8 to 7.11-7.33 during week 2 and increased to peak values of 7.91-8.33 during week 3. It thereafter decreased to lowest values (6.07-6.31) during week 6 before increasing to final values of 6.87-7.13. The PM and SM treatments varied in similar fashion (Figs. 2a and b). After initial increase during week 1, the pH decreased slightly during week 2 in all the treatments (7.27-7.51; PM and 6.97-7.11; SM) before increasing to peak values during week 4 (8.43-8.60; PM and 7.63-7.87; SM) and decreasing again to lowest values during week 7 in PM treatments (6.33-6.43) and week 6 in SM treatments (6.13-6.53). The increase in pH during digestion could be attributed to subsequent transfer and consumption of volatile fatty acids during methanogenesis while the decrease implied the production of volatile fatty acids (Cuzin *et al*., 1992). The attainment of pH values >5 during digestion showed that there was efficient methane production (Jain and Maattiasson, 1998). Cow dung treatments had the lowest final pH values (6.87-7.1) followed by SM treatments (7.07-7.30) and PM treatments (7.43-7.57). The final pH values were within the range of 6.0-8.5 for organic matter compatibility with most plants (Lasaridi *et al*., 2006).

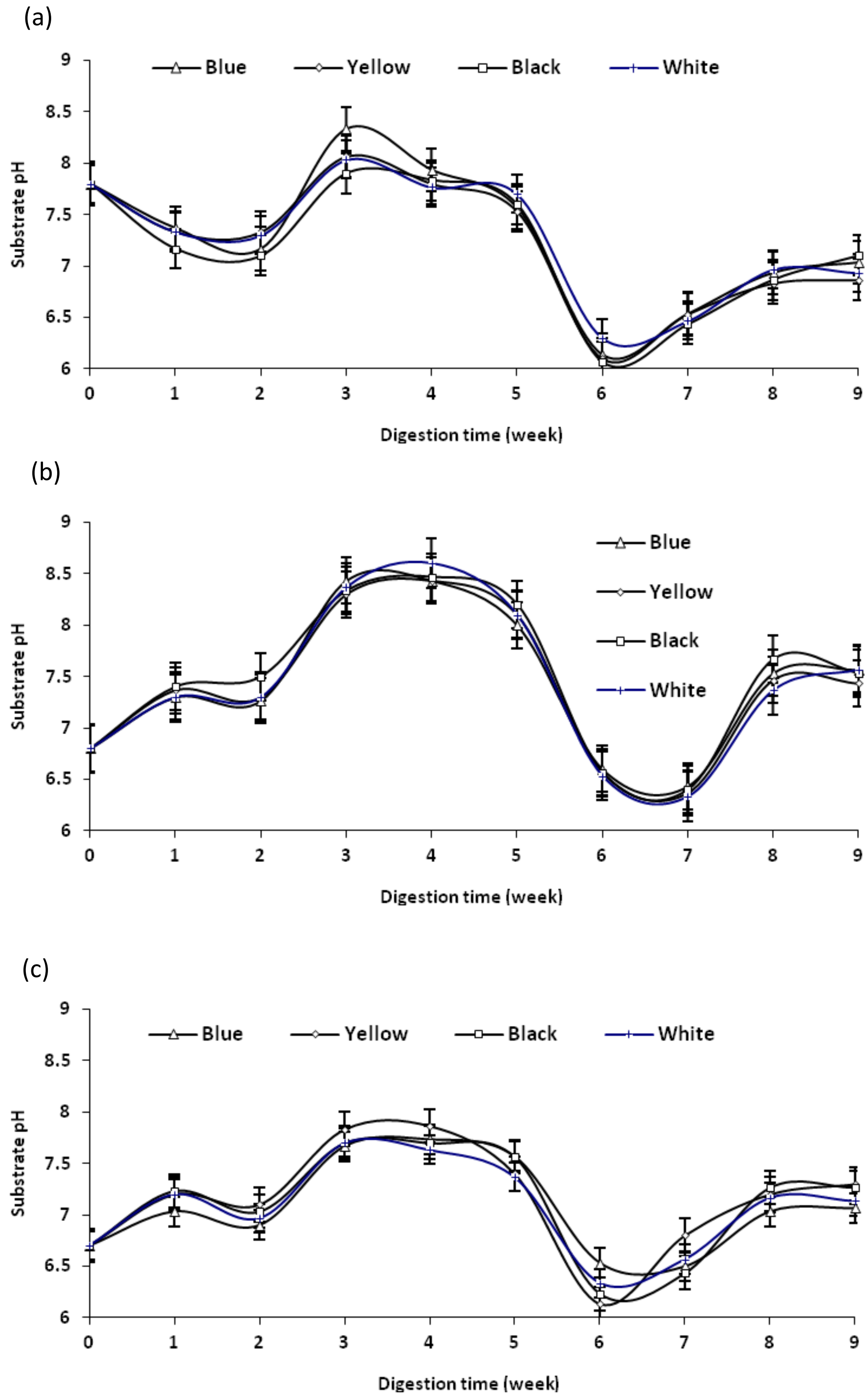


Figure 2. Profile of weekly pH during digestion in (a) Cow dung, (b) Poultry manure and (c) Swine manure.

Biogas yield

The results showed that DCo and MT had significant ($p \leq 0.05$) effect on biogas yield (Table 2). Poultry manure produced the highest average yield while CD produced the least (Table 3). On the average, the highest biogas production was in the black biodigester, followed by blue, yellow and white in that order (Table 3).

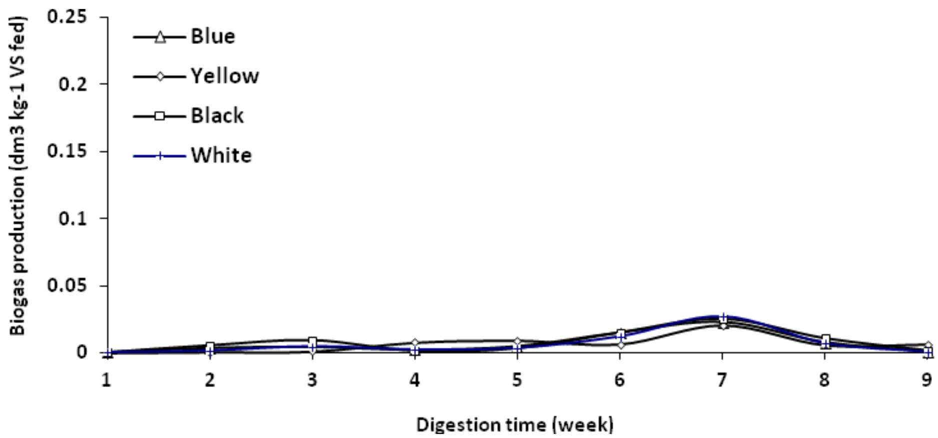
Table 3- Duncan's Multiple Range Tests showing the significant means within measured parameters

Parameter	Manure type			Digester colour			
	CD	PM	SM	Blue	Yellow	Black	White
Temperature (^oC)	29.0^{a}	29.9^{a}	29.7^{a}	29.6^{a}	29.3^{a}	29.7^{a}	28.9^{a}
pH	7.16^{b}	7.46^{a}	7.13^{b}	7.25^{a}	7.25^{a}	7.25^{a}	7.24^{a}
Biogas ($dm^3\ kg^{-1}$ VS fed day^{-1})	6.85^{c}	57.9^{a}	27.3^{b}	32.5^{ab}	29.5^{b}	34.2^{a}	26.5^{c}

CD: cow dung, PM: poultry manure, SM: swine manure. Means with the same letter along the row are not significantly different ($p<0.05$)

However, the blue biodigester yielded the same quantity ($p > 0.05$) as the black biodigester. The daily biogas yields were averaged weekly and presented in Fig. 3. All the treatments had fluctuating productions especially at the initial stage with some days recording zero production. This might be due to the wet weather and fluctuating tempertures during this period of the experiment. However, production picked up faster in PM treatments (Fig. 3b) than in other treatments. This might be attributed to the high degree of biodigestibility of poultry manure as indicated by its low C:N ratio of 27.6 (Table 1). Generally, the total non-production days were 106, 104, 100 and 94 days for white, black, yellow and blue digesters, respectively while SM, CD and

(a)



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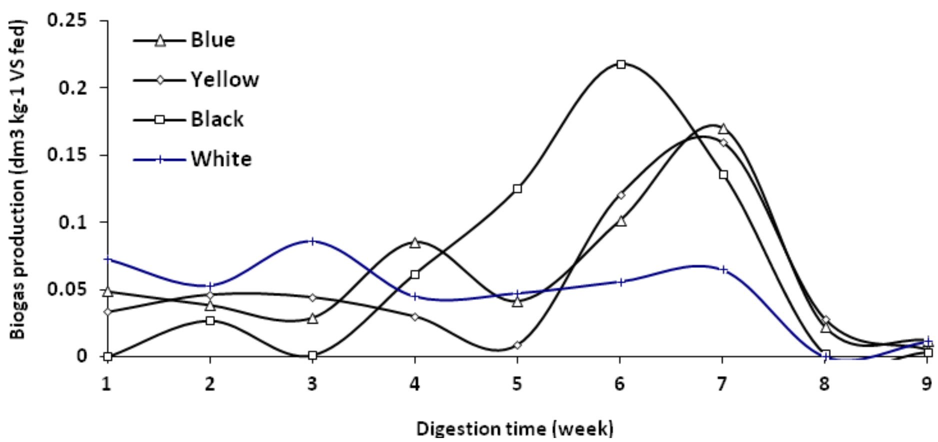

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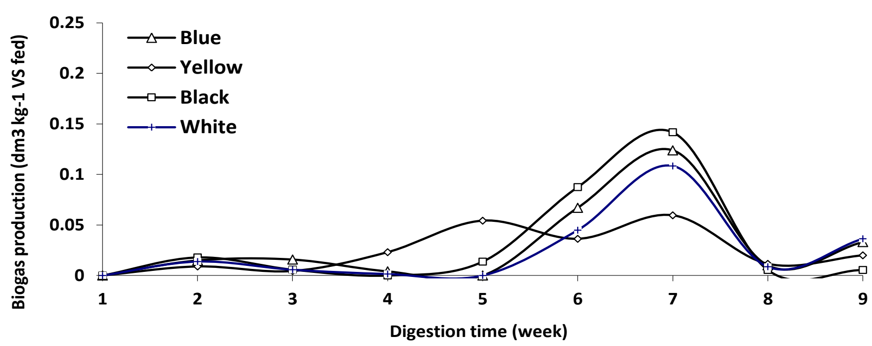

Figure 3. Weekly biogas yield during digestion in (a) Cow dung, (b) Poultry manure and (c) Swine manure.

PM treatments had 146, 139 and 119 non-production days, respectively. This showed that the blue biodigester had the most stable biogas production despite its slightly lower yield compared to black biodigester. Poultry manure had the most stable biogas production among the manures which, is attributable to its high degree of biodigestibility. The biogas production exhibited a sinusoidal pattern which was most obvious in PM treatments with almost all the treatments having their peak productions during week 7 (Fig. 3). The fact that the black biodigester had the highest yield of biogas from each manure while the white biodigester had the least could be related to the high and low emissivity values of 0.95 and 0.84 for black and white plastics, respectively. Furthermore, the non-significant ($p > 0.05$) difference in the yields of black and blue biodigesters could also be related to their close emissivity values (0.95 and 0.94, respectively). The low yield observed in CD substrates compared to high yield observed by Ogunwande *et al.* (2015) may be as a result of low and high concentrations of crude protein and total fiber, respectively of CD compared to PM and SM (Chen *et al*., 2003). The cumulative profile (Fig. 4) showed that the black biodigester maintained the highest yield in CD treatments whereas in PM treatments, it recorded the least yield until day 29 before it increased to the highest yield by day 41 and afterwards. Similarly, biogas production in the black digester increased to the highest yield by day 44 and afterwards in SM treatments.

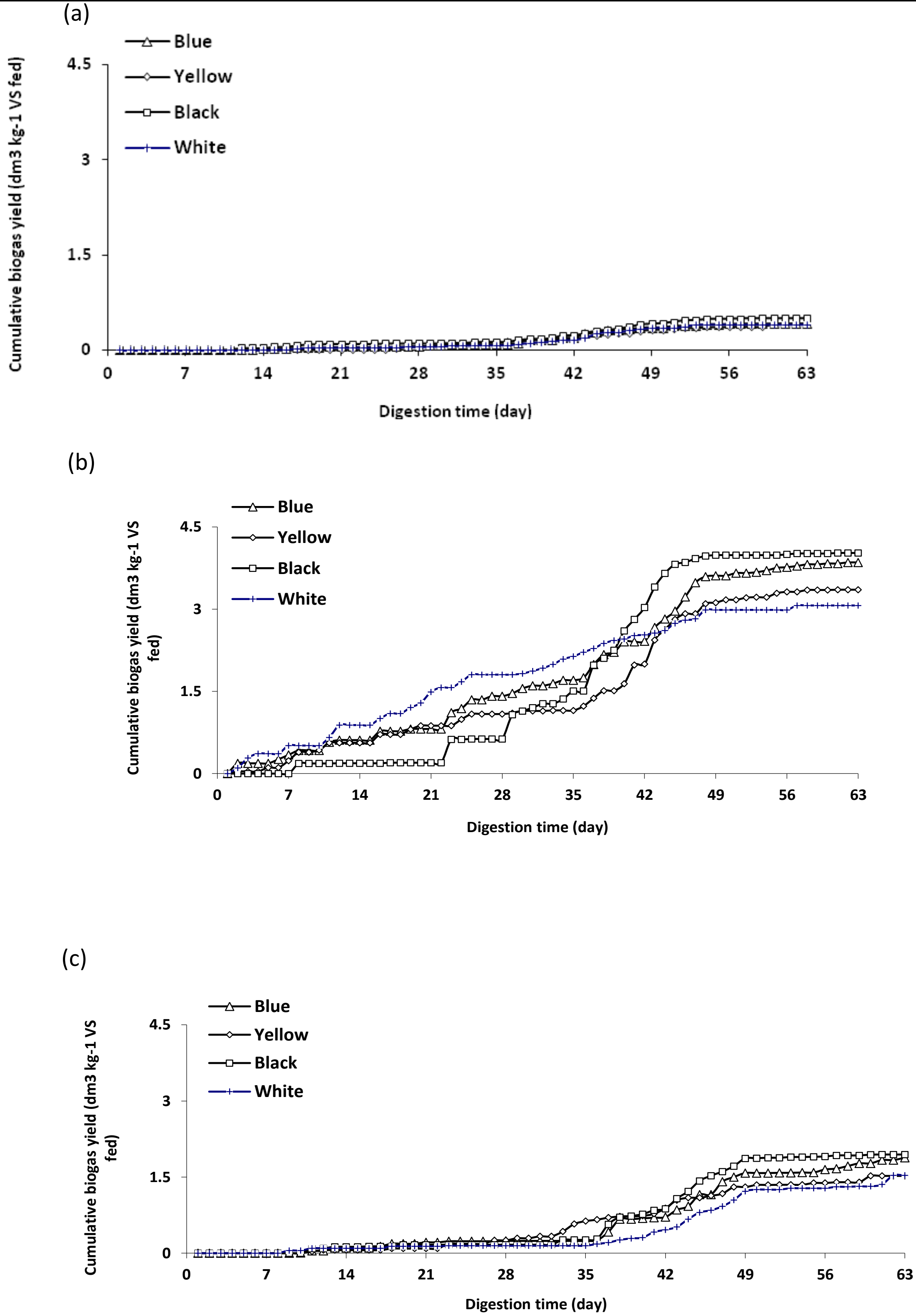

Figure 4. Cumulative biogas yield during digestion of (a) Cow dung, (b) Poultry manure and (c) Swine manure.

Conclusions

Biodigester colour and manure type had significant effects on biogas yield. The highest and lowest yields were recorded in black and white biodigesters, respectively. Poultry manure produced higher yield than swine manure and cow dung. The blue biodigester and poultry manure appeared to have more stable biogas production during digestion. The non-significant difference in biogas yields of the black and blue biodigesters showed that blue colour is promising for enhancing the performance of plastic biodigesters.

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