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Agricultural Potential of Biosolids Generated from Dewatering of Faecal Sludge on Unplanted Filter Beds.

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Abstract
The study was conducted to determine the agricultural potential of biosolids produced from the dewatering of faecal sludge on drying beds in Ghana. It was conducted using bench scale filter beds at KNUST in Kumasi, Ghana. Different filter media were used to dewater FS while different loading rates of FS were dewatered on selected filter medium. Different percentages of sawdust mixed with FS were also dewatered and biolsolids produced were dried and analysed for nutrients and heavy metals. The results showed that the average percentage carbon in all the biosolid ranged between 27 and 42.7%, nitrogen was 1.82 – 3.54% and carbon – nitrogen ratio ranged between 8.7 - 23.9%. The level of phosphorus and potassium ranged between 1.73 – 3.69%and 0.81- 3.78% respectively. The average concentration of heavy metals analysed in the dried biosolids were very low where the range of Cu was 0.081- 0.157mg/kg, Fe 1.530- 4.562mg/kg, Pb 0.009- 0.032mg/kg. Cd, Mn, and Zn showed ranges of 0.036 – 0.092, 0.076-0.652 and 0.026-0254 mg/kg respectively.
Key words: Biosolid, dewatering, faecal sludge, heavy metals, nutrients.

1.0 Introduction

New approaches in human waste management postulates that sanitation systems should, whenever feasible, be conceived and managed in a way that enables the recycling of organic matter and nutrients contained in human excreta (Winblad ,1997). A change in the sanitation management paradigm from flush-and-discharge to recycling of urine and faeces is gaining ground in Europe (Otterpohl, 2000). As a consequence, treatment strategies and technological options for faecal sludges and solid waste will have to be developed which allow the optimum recycling of nutrients and organic matter to peri-urban agriculture, while being adapted to the local situation and needs.

Use of untreated municipal wastes to enhance productivity and soil quality could lead to significant health risks derived from the spread of excreta related diseases and chemical contamination of the food chain (Owusu-Bennoah and Visker, 1994). Nevertheless, it is considered that where sludge can improve agricultural productivity, independently of its microbial characteristics, it improves the nutritional status of a population lacking food, thus improving public health (IWMI, 2003)

The organic and solids content as well as ammonium and helminth egg concentrations measured in FS are normally higher by a factor of 10 or more in FS than in sewage or domestic wastewater (Montangero and Strauss, 2000). It has been recommended that due to high variability in faecal sludge characteristics, the design of a treatment system should be based on case-to-case results, and should include a first treatment step consisting of separating solids from liquid. Methods for solids–liquid separation of FS have been reported (Strauss *et. al.,* 2000). In Ghana, stabilization and settling ponds have been the method-of-choice to date. However, system based on this option prove little effective where fresh undigested and highly concentrated FS from public toilets form a major fraction of the FS delivered to the treatment plants. In most cities in Ghana, public toilet sludge (PTS) form up to 50% of the FS collected (http://www.ghanadistricts.com/districts1on1/kma/?arrow=atd&_=6&sa=5492; assessed 12/4/2011).

Large volumes of faecal sludge generated in urban centres of most developing countries, coupled with indiscriminate disposal of liquid and solid waste in the environment have led to rampant outbreak of sanitation related diseases. In addition to this are the large amounts of nutrients (N and P) washed from these organic matter into water bodies causing eutrophication and consequent fish kill and the loss of the aesthetical beauty of the environment.

Harmful though the faecal sludge with its associated pathogen load could be, it can be made beneficial and very useful if well handled and treated so that incorporating the nutrients into the soil for agricultural production through recycling will not pose such hazard. Leitzinger (2000) reported that urban and peri-urban agricultural soils are usually depleted of organic matter and nutrients (N and P). According to Drangert, (1998), every person's excreta is in theory at least, nearly sufficient to grow one's own food. A material flow study conducted in the City of Kumasi, Ghana, found that for urban and peri-urban agricultural soils, nutrients (N and P), organic matter, could be fully replenished by using all the human waste and recycling all the organic market waste and the wastes from breweries, timber and food processing factories and from chicken farms. However, most of these wastes would have to be treated prior to use (Leitzinger, 2000).

Numerous options for treatment of faecal sludge are available of which solid-liquid separation using unplanted drying beds is among the potentially feasible ones. This method is among the lot prescribed for developing and newly industrialized countries. It is comparably more favourable to others with respect to logistics, land requirement and duration of cycle.

Preliminary results showed that unplanted drying beds were effective in dewatering FS and produce biosolids after which the product of co-compost could be safely recommended for agriculture (Koné and Strauss, 2004).

2.0 Materials And Methods

The study was conducted at Kwame Nkrumah University of Science and Technology (KNUST) in Kumasi, the second largest city of Ghana. Bench scale drying beds were used to carry out the dewatering of faecal sludge. The studies consisted of different methods of improving the dewatering of faecal sludge using unplanted filter bed to produce biosolids for crop production. It looked at the nutrient potential and the heavy metal concentrations of the biosolids so produced.

2.1 Filter bed preparation

Each filter bed was raised in a cylindrical plastic container having a size of 0.85m long 0.175m diameter. Coarse and fine gravel of about 2.0-3.0 cm and 0.5-1.0 cm diameter respectively, served as base support for the filter medium (sand). The base of the filter bed was filled with the course gravel to a depth of 15cm, followed by the fine gravel to a depth of 10cm, with the sand on top to a depth of 20cm. Nylon net was placed on the sand on which the FS was poured, to ensure easy removal of the dewatered biosolid. A wooden structure of size 4.5m long by 3.5m wide and 2m high was raised and roofed with iron sheets to cover the filter beds. A wooden table of 3m long, 2m wide and 0.4m high was constructed under it which served as a platform for raising miniature filter beds.

2.2 Collection of faecal sludge samples

The faecal sludge used for the dewatering consisted of public toilet sludge (PTS) and septage. Public toilet sludge and septage were collected in separate plastic drums of about 90 litres each from Kumasi Waste Treatment Plant in Kumasi in Ashanti Region of Ghana. The drums of FS were then transported to the project site for mixing. The public toilet sludge (PTS) and the septage were mixed in various proportions (1:1, 1:2 and 1:3), for further application on the drying beds.

2.3 Methods of dewatering

The dewatering activities involved three main phases depending on the objective under consideration. These included, (i) dewatering of FS using filter media of different particle sizes,(0.1 – 0.5, 0.5 – 1.0, and 1.0 – 1.5mm) denoted as FM1, FM2 and FM3 respectively. (ii) dewatering of FS of different solid loading rates of Public toilet sludge(PTS) and septage in the ratio of 1:1, 1:2 and 1:3 denoted as SLR1, SLR2 and SLR3 respectively, using filter media of particle sizes between 0.1 – 0.5 mm, denoted as FM1, and (iii) mixing different percentages of sawdust with faecal sludge (selected from specific objective two) and dewatering on a selected filter medium (selected from specific objective one).

2.4 Sample preparation

The biosolid collected from each filter bed was well mixed in a plastic bowl using a wooden stick. About 50 g was collected and oven dried at 105 ^oC for 24 hours. It was packaged in a clean plastic sheet and kept in refrigerator. The biosolids from all the filter beds were treated the same way. After completing all the cycles, all the dried samples were analysed for nutrients (carbon, nitrogen, phosphorus and potassium), and heavy metals (copper (Cu), iron (Fe), lead (Pd), cadmium (Cd), zinc (Zn) and manganese (Mn).

A modification of the wet oxidation procedure based on the reduction of the $Cr_2O_7^{2-}$ ion by organic matter which is known as the Wakley and Black procedure was employed to analyse carbon (Okalibo, *et. al.* 2002). The total nitrogen in dried faecal sludge and biosolid was determined using the block digester method as described by Okalibo, *et. al*. (2002). The total phosphorus was determined by the caloric procedure for total phosphorous measurement without pH adjustment as described in, Laboratory Methods of soil and plant analysis (Okalebo *et. al*. (2002). The potassium was determined using the method as described in, Laboratory Methods of soil and plant analysis, (Okalebo *et. al*. (2002). The heavy metals were measured in a digest obtained by treating samples with an acid mixture made from concentrated nitric acid, concentrated sulphuric acid, and perchloric acid, as described in Chapman and Pratt, (1961); Association of Official Analytical Chemist,(1979).

3.0 Results And Discussion

3.1 Characteristics of nutrients and heavy metals

The percentage carbon (%C) in the dried biosolids from the different filter media were 36.0%, 34.0% and 33.0% for FM1, FM2, and FM3 respectively, which were lower than %C obtained in the dried raw FS. The percentage nitrogen (%N) in the dried biosolids obtained from FM1, FM2, and FM3 were, 3.01%, 2.45% and 2.29% respectively. The percentage phosphorus (%P) and percentage potassium (%K) in the dried biosolid from FM1, FM2 and FM3 were, 2.05, 1.98 and 1.73(%), and 1.04, 0.93 and 0.81(%) respectively. All the values were lower than their corresponding values in the dried raw FS, (Table 1). The C:N ratio of the dried biosolids from FM1, FM2 and FM3 which showed values of 12.0, 13.9 and 14.4 were however greater than the corresponding value in the raw FS (Table 1). The percentage values obtained for all the nutrients decreased from FM1 to FM3. The concentration of all the metals analysed (Cu, Fe, Pb, Cd, Zn and Mn) (mg/kg) in the dried biosolids decreased from the FM1 to FM3 (Table 1). The dried biosolids concentrations were all lower than their corresponding values in the dried raw FS.

Table 1: Nutrients and Heavy metals in dried biosolid from different filter media (N = 6)

	Nutrients as % TS					Heavy metals (HM) as mg/kg					
Filter media (FM)	**C:N**	**%C**	**% N**	**%P**	**%K**	**Cu**	**Fe**	**Pb**	**Cd**	**Zn**	**Mn**
FM1	12.0	36.0	3.01	2.05	1.04	0.190	4.38	0.019	0.073	0.325	0.148
FM2	13.9	34.0	2.45	1.98	0.93	0.188	3.35	0.017	0.061	0.301	0.132
FM3	14.4	33.0	2.29	1.73	0.81	0.081	2.04	0.009	0.089	0.257	0.105
Raw FS	**10.2**	**38.10**	**3.72**	**3.06**	**2.93**	**0.116**	**4.43**	**0.022**	**0.083**	**0.496**	**0.150**
LSD	1.906	2.258	0.647	0.586	1.004	0.054	1.123	0.006	0.012	0.104	0.021
Limit of HM in biosolids (USA). From Salvato, 1982 (mg/kg)						95-700		200-500	10-400	1000-1800	
Limit of HM in Developing countries, Hornwerg et al, (2000). (mg/kg)						80.000		150	3.0	300	

C, N, P and K = % TS; Cu, Fe, Pb, Cd, Zn and Mn = mg/kg

3.2 The quality of dried biosolids dewatered from different solid loading rates

The percentage carbon (%C) of the dried dewatered biosolids decreased from 30% in SLR1 to 28% in SLR2 but increased to 31% in SLR3, whereas in the raw dried FS it increased from 37.7% in SLR1 to 39.8% in SLR3 (Table 2). The percentage nitrogen (%N) in the dried dewatered biosolid decreased from 3.45% in SLR1 to 2.23% in SLR3 and it correspondingly decreased from 3.65% to 2.98% in SLR1 to SLR3 of the dried raw FS. The ratio of the %C and %N resulted in an increasing C:N ratio from 8.7 in SLR1 to 13.9 in SLR3, in the dried biosolids. It again increased in the dried raw FS from SLR1 to SLR3. The percentage (%P) of 3.08% in SLR1 decreased to 2.18% in SLR3 of the dried dewatered biosolid. The percentage (%K) in the dried dewatered biosolid decreased from 1.05% in SLR1 to 0.84% in SLR3. The %P and %K again decreased from SLR1 to SLR3 in the dried raw FS (Table 2). The heavy metals analysed showed increasing values in Fe, Zn and Pb from SL1 to SLR3 in the dried dewatered biosolid and dried raw FS, whereas Cu, Cd and Mn decreased from SLR1 to SLR3 in the dried dewatered biosolids and the dried FS. The concentrations of the heavy metals of the dried FS samples were higher than their corresponding dried dewatered biosolid concentrations (Table 2).

Table 2: Nutrients and Heavy metals (HM) in dried dewatered biosolid from different solid loading rates (SLR) of raw faecal sludge (FS)

	Nutrients as % TS					HM as mg/kg					
Solid Loading Rate	**C:N**	**%C**	**% N**	**%P**	**%K**	**Cu**	**Fe**	**Pb**	**Cd**	**Zn**	**Mn**
SLR1 (db)	8.7	30.0	3.45	2.18	1.05	0.225	2.127	0.014	0.059	0.282	0.026
SLR2 (db)	9.5	28.0	2.96	2.43	0.96	0.176	2.952	0.017	0.038	0.364	0.112
SLR3 (db)	13.9	31.0	2.23	3.08	0.84	0.142	3.986	0.018	0.039	0.451	0.208
Raw FS (SLR1)	10.3	**37.7**	**3.65**	**3.22**	**3.78**	**0.145**	**4.423**	**0.022**	**0.092**	**0.532**	**0.201**
Raw FS (SLR2)	10.8	**35.5**	**3.28**	**3.17**	**3.18**	**0.188**	**4.562**	**0.026**	**0.085**	**0.592**	**0.254**
Raw FS (SLR3)	13.4	**39.8**	**2.98**	**3.14**	**3.09**	**0.128**	**4.506**	**0.031**	**0.076**	**0.652**	**0.230**
LSD	1.716	3.818	0.407	0.366	1.091	0.030	0.817	0.005	0.019	0.114	0.070

db = dried biosolid

3.3 Quality of dried faecal sludge and dried biosolid dewatered from sawdust-faecal sludge (SD-FS) mixture.

The dried dewatered biosolids were obtained from dewatering 50%, 100%, 150% and 0% sawdust-faecal sludge (SD-FS) mixture on filter beds. The percentage carbon (%C) in the dried dewatered biosolid increased as the percentage sawdust (% SD) increased thus the control had the least %C of 34.0 while the 150% SD mixture had the highest %C of 43.5. The %C in the dried dewatered biosolids of all the treatments were lesser than the dried raw FS, except the dried dewatered biosolid from the 150% SD-FS mixture. The percentage nitrogen (%N) was higher in the dried raw FS than the dried dewatered biosolids (Table 3). The %N in the dried dewatered biosolid decreased as the percentage of sawdust increased, thus the 0% sawdust treatment had the highest %N of 3.18 while the 150% sawdust treatment had the least %N of 1.82. This consequently affected the C:N ratio, which therefore increased as the percentage sawdust increased (Table 3). The %P in the dried biosolid of the 0% sawdust treatment (control) which was 3.04 was the highest among the treatments and it decreased as the percentage sawdust increased. The 150% sawdust treatment therefore had the least %P of 1.95. The percentage of potassium (%K) rather increased as the percentage of sawdust increased, thus the 0% sawdust treatment had the least %K of 0.94 while the 150% treatment had the highest %K of 1.67.The %P and the %K in the dried faecal sludge were higher than their corresponding dried biosolids (Table 3). Copper (Cu) and iron (Fe) in the dried biosolids decreased as the percentage sawdust increased. Lead (Pb) was extremely small in all the samples but was higher in the dried raw faecal sludge than the dewatered biosolids. Cadmium (Cd), zinc (Zn) and manganese (Mn) were all higher in the raw FS and decreased in the dried biosolids as the percentage sawdust increased (Table 3) thus the control had the highest concentration in the dried biosolids while the 150% SD treatments had the least concentrations.

Table 3: Nutrients and Heavy metals in dried dewatered biosolid from different sawdust-FS mixture (N = 6).

	Nutrients as % TS					Heavy metals (HM) as mg/kg					
% Sawdust Added	C:N	%C	% N	%P	%K	Cu	Fe	Pb	Cd	Zn	Mn
50% SD	15.7	37.0	2.35	3.69	1.28	0.122	2.209	0.022	0.055	0.414	0.130
100% SD	18.3	40.0	2.18	2.47	1.55	0.105	2.265	0.021	0.036	0.128	0.093
150% SD	23.9	43.5	1.82	1.95	1.67	0.069	1.530	0.015	0.045	0.076	0.052
0% SD	10.7	34.0	3.18	3.44	0.94	0.157	3.754	0.024	0.047	0.542	0.205
Raw FS	**12.1**	**42.7**	**3.54**	**3.39**	**2.20**	**0.156**	**4.328**	**0.032**	**0.072**	**0.449**	**0.218**
LSD	4.725	3.553	0.644	0.667	0.418	0.033	1.048	0.006	0.012	0.185	0.064

C, N, P and K = % TS; Cu, Fe, Pb, Cd, Zn and Mn = mg/kg

Faecal sludges are usually "cleaner" than sewage treatment plant sludges, as they tend to contain less heavy metals or refractory organics. Exceptions may be found in places where septage is also collected from septic tanks serving cottage or small industrial enterprises (Montangero and Strauss, 2002).

The dried dewatered biosolids and the dried FS analysed showed organic carbon content ranging between 28.0 and 43.5 %. These values of percentage carbon showed significant improvement well above values obtained in collaborative research conducted by IWMI, SANDEC, KMA and KNUST, (Cofie, 2003), at Buobai in Kumasi, Ghana, on co-composting of dried faecal sludge (DFS) and municipal solid waste (MSW), where analyses of dried faecal sludge (DFS) gave 11.4% carbon content. Drangert *et. al*., (1998), through their analyses of human excreta also obtained 11.7% carbon content. These percentage carbon (%C) compared well with municipal solid wastes of developing countries whose content have been found to contain about 40 -85% biodegradable organics of which 30-40% is C. The percentage carbon of the sawdust-FS mixtures which ranged between 37.0 and 43.5% compared well with literature compiled by Arends, (1985), in which different wood materials showed carbon content of between 43.2% and 49.8%. The high carbon content of the dried FS might be attributed to the dietary content of the people in most developing countries and for that matter, Ghana, whose basic diet is mostly rough carbohydrates. It might partly depend on the type of FS generated, without addition of storm water or industrial waste as found in the developed world. The high organic carbon as found in this type of dried biosolids and FS is very essential if the use of the biosolid for soil amelioration is paramount. Epstein (2003), asserted that organic carbon increased linearly with biosolid application, and 4 years after application, there was three times as much carbon in the high biosolid application rate soils. Again Epstein (1973, 1975), indicated that organic matter through the activity of microorganisms increases soil aggregation. Adding biosolids and sludge increased the hydraulic conductivity of soils. Organic matter through the addition of biosolids reduced bulk density and increased total porosity and moisture retention of soils (Clapp *et. al.,* 1986).

The percentage nitrogen (%N) within the range of 1.82% and 3.72% obtained in the samples from the different treatments in this studies was higher, compared to the ranges of 1.3 – 1.6 % N, being nitrogen levels of human wastes used as raw materials for compost (Shuval *et. al.,* 1981; Obeng and Wright, 1987). The % N values in this study were higher than that of the raw FS applied in the pilot co-composting at Buobai in Kumasi which contained average N of 0.9% (Cofie, 2003). Analyses of feaces and human excreta by Strauss in developing countries produced 4-7% N and 9-12% N of dry TS respectively (Strauss, 1985). Although these values were comparatively higher, the analyses were made from fresh samples of feaces and excreta. The high nitrogen content of the dried biosolids obtained from the dewatering by the unplanted beds serve as good basis for its application in the soil for crop production or as good compost/co-compost material. The organic nitrogen in biosolids applied to land undergoes numerous transformations which are extremely important since they affect plant growth (Epstein, 2003). Chae and Tabatabai (1986) indicated that the rate of nitrogen mineralization is dependent on moisture, temperature, C:N ratio and biosolids properties. Parker and Sommers (1983) found that amount of mineralisable nitrogen in biosolids was proportional to the total organic nitrogen. The foregoing emphases indicate the importance of nitrogen in biosolids. Since the organic matter in biosolids incorporated into the soil begin to decompose while the microorganisms utilize the carbon as a source of energy and nitrogen for cell development and growth, the C:N ratio becomes very important. Hoornweg *et. al.,* (2000), states that the C:N ratio of the final product (compost) should be lower than 22. Good compost is about 10:1 C:N ratio (Bollen and Glennie, 1959). The C:N obtained for these dewatering schemes which ranged between 8.7 and 23.1 can be described as good for composting or for direct application on the land. The highest C:N ratio recorded by 150% SD-FS treatment is high enough to make a good composting material. It compares well with C:N of 31.4 for household waste, 28.5 for Municipal waste and 21.8 for dried faecal sludge which were recorded by Cofie *et. al.,* (2006) in their pilot co-composting project carried out at Buobai near Kumasi.

Phosphorus (P) is an essential plant nutrient. It has been stated that, P deficiency is the second most important soil fertility problem throughout the world (Lindsey *et. al.* 1989). However excessive amounts of P in the soil tend to immobilize other chemical elements such as zinc (Zn) and copper (Cu) that are also essential for plant growth (Chang, *et. al*.1983). The %P obtained from the dried biosolids and dried FS which ranged between 1.73% and 3.39% compares well with percentages of 4.0, 3.7 and 3.8 obtained for dried feaces, urine and excreta reported by Strauss in developing countries (Strauss, 1985).

Epstein reported that potassium (K) in biosolids is generally low since K compounds in wastewater are soluble, they do not settle in biosolids (Epstein, 2003). This assertion is actually reflected in these analyses where the dried raw FS had %K ranging between 2.2 and 3.78% while the dewatered biosolids ranged low between o.64 and 1.67% meaning that a lot of the K went into the filtrates. However all the %K obtained in the dried biosolid samples compared well with what Strauss reported, which were 1.6% for feaces and 2.7% for excreta. It also compares well with %K values of the starting compost materials of the pilot co-composting project at Buobai in Kumasi. Potassium is an essential element for plant growth. It is also important in amino acids and protein synthesis and photosynthesis.

Copper (Cu), iron (Fe), zinc (Zn), manganese (Mn), lead (Pb) and cadmium (Cd) analysed in this research were classified as heavy metals. Copper is important in many roles including photosynthesis, respiration, enzymes, reproductive growth, and seed and fruit yield (Romheld and Marschner, 1991). Iron is essential to plants, animals and humans. It is a component of protein. It affects photosynthesis, respiration, sulphur reduction and nitrogen fixation (Romheld and Marschner, 1991). Zinc is involved in carbohydrate metabolism as well as

proteins and auxins. It is important in stabilisation and structural orientation of certain membrane proteins. Cadmium (Cd) is toxic to animals and man. It is retained in the kidney and the liver and is probably related to the mental binding protein matallothionein (Kagi and Valee, 1960). It has been indicated that a 25% yield reduction for various crops resulted when Cd concentration ranged from 7 to 160 µg/g dry weight (Millner *et al.,* 1976; Bingham, 1979). Lead (Pb) is non essential element to humans, animals and plants but is toxic to humans. Generally, toxic intake is 1mg and lethal intake is 10g but the lethal intake for many animals occur at about 10 mg (NRC, 1980). From the above discussions it is understood that low concentrations of these heavy metals in the soil may affect the plant growth or their high concentration in the soils may affect plants growing in the soils or animals and humans that feed on it. This therefore makes their presence in the biosolids very important especially when there is reuse consideration as fertiliser. The concentrations found in the dried dewatered biosolids and the dried FS analysed recorded low concentrations that make them insignificant to cause any concern. They were far below the samples used for the pilot co-composting at Buobai (IWMI *et al.*, 2003). All were over 100 – 1000 times lower than the corresponding concentrations reported in US and Canadian biosolids (Lue- Hing *et. al*, 1999). They were also about 10 – 100 times lower than their corresponding concentrations that occur in the commercial inorganic fertilisers (Bowhay, 1997).
The high level of nutrients and low concentrations of heavy metals recorded in the dried faecal sludges and the dried bioslids are good characteristics for the bioslids to be recommended for co-composting.

4.0 Conclusion and Recommendation

4.1 Conclusion

The percentage carbon of all the dewatered biosolids from the filter beds were high enough to be used for composting or co-composting. It further increased with the biosolids of the faecal sludge-sawdust mixture as the percentage of the sawdust increased.
The percentage nitrogen in all the dried dewatered biosolids obtained from the dewatering schemes was within levels to be used as compostable materials.
Other nutrients like phosphorus were also within levels described as good for composting/co-composting.
The concentrations of all the heavy metals analysed in the dried dewatered biosolids were too low to be source of concern when the biosolids are to be considered as soil ameliorants.

4.2 Recommendation

It is therefore highly recommended that the biosolids produced from faecal sludge dewatered on unplanted filter beds is a good compostable material either for composting or co-composting.

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