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Animal Manure-Impact on Human Health and Climate Change

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***Abstract* – Manure production has been significantly affected by the increasing demand for animals and animal products worldwide; thereby, leading to a great concern regarding animal waste management as it constitutes a great environmental menace to soil and water bodies 'as well as greenhouse gases emission which directly impacts human, animal, and environmental health. Animal manure is a rich source of zoonotic pathogens that are capable of causing disease in humans and also contribute significantly to the total agricultural emissions of nitrous oxide and methane which are key to global warming. Based on papers published in journals indexed in SCI-Expanded on the Web of Science, this article provides a bibliometric analysis on manure management from 2010 to 2021. According to the poll, 1258 authors contributed to the documents being examined. From the documents analyzed, Czymmek, K.J. (n = 6) was one of the relevant authors. In Africa, South Africa had the highest publication (n = 10), and the least was observed in Kenya (n = 4). In terms of country, the United States of America is the most cited country with 209 publications and 1126 citations followed by China with 99 publications and 537 citations. Therefore, this study holistically reviews the risk posed by animal waste, recent trends in manure management towards nutrient stabilization, pathogen reduction, reduced volatile organic emissions, and greenhouse gases, as well as a bibliometric analysis of currently published articles.**

***Keywords* – Animal Waste, Climate Change, Manure Management, Human Health, Pathogen, Bibliometric Analysis, Environmental Health, Soil Nutrient Stabilization.**

I. INTRODUCTION

Animal manure had been used by farmers for centuries and it is a major component of organic and sustainable agricultural production globally. It is very rich in organic matter and macro and micro plant nutrients and the derived benefits range from improvement of soil physical, chemical, and biological properties, organic food products to effective management of waste (Adegunloye *et al*., 2007). However, the direct application of manure waste to agricultural fields has been reported as a potential source of contamination of fresh produce through microbial pathogens and pathways for antibiotic residue uptake. Run-off of veterinary antibiotics sediments, zoonotic pathogens, and emission of Green House Gases (GHGs) have been considered as part of the recent environmental threats.

Zoonotic pathogen contamination and antibiotic residue traces in water and horticultural produce increase as demand for animal and animal products increases by day (Pell, 1997, Prosser and Sibley, 2014). Jones *et al.* (2017) reported the impact of the current global development in ecological systems such as increased human population and consumption, globalization, urbanization, climate change, loss of habitat, and biodiversity on the emergence and re-emergence of the zoonotic pathogen of economic importance worldwide. The most common zoonotic pathogen and antibiotic residues found in fresh horticultural produce such as lettuce, cabbage, carrot, and cucumber are *Salmonella* spp, *Escherichia coli* 0157:H7, *Mycobacterium paratuberculosis* and tetracyclines, oxytetracycline, tylosin, sulfamethazine, respectively (Kumar *et al*., 2004, Kumar *et al*., 2005).

Manure management has received global awareness as a major anthropogenic source of methane and nitrous oxide which are deleterious GHGs through anaerobic decomposition, nitrification, and denitrification of animal manure (Pitesky *et al*., 2009). Manure contains various nutrients and organic compounds (carbon and nitrogen) and during its build-up, storage, and field application, there is an emission of gases such as ammonia (NH_3) and GHGs like methane (CH_4) and nitrous oxide (N_2O) (Chadwick *et al*., 2011, London, 2018, Webb *et al*., 2012). Pollutions from animal manure contribute greatly to water, soil, global warming, and loss of biodiversity (Steinfeld *et al*., 2006). Attaining Global One Health to protect the plant, human, animal, and environmental health will remain a mirage in the animal sector if manure management is not holistically reviewed. The Sustainable Development Goals (SDGs 3, 6 & 13) suggest a prominent pathway to connect human, animal, environment and ecosystem health through a more integrated approach (Queenan *et al*., 2003). Some countries like the United States of America and France have legislations (National Organic Programme Regulations) on the use of raw animal manure in organic farming to avoid or minimize environmental and pathogenic pollution; however, most African countries do not have regulations regarding it; therefore, there is an urgent need to move towards an integrated approach using available resources.

This study will therefore elucidate manure management or handling methods that are capable of reducing of emission GHGs and zoonotic pathogen in animal manure and also examine the researches that have been done on animal manure and the associated risk of animal manure on human health and the environment.

II. BIBLIOMETRIC ANALYSIS OF ANIMAL MANURE UTILIZATION RESEARCH OUTPUT

Various scientific databases can be sourced for information on bibliometric analysis of research publications on a specific subject of interest (Redeker *et al*., 2019, Simoes *et al*., 2021). Web of Science (WoS) is one of the most consistent and inclusive databases for bibliometric analysis with millions of varying-quality scientific articles (Can-Güven, 2021). Consequently, WoS core collection was chosen for data on bibliometric analysis of research trends on improved animal manure management from 2010 to 2021.

The following search strategy was used: TITLE (Manure* management). A total of 298 documents were retrieved and further refined to documents originally written in English (n = 289). Furthermore, we validated manually and removed those articles that are not within the time range and do not relate to our focus, as well as false-positive, of which 3 articles were excluded from the documents. 286 articles were found suitable for bibliometric analysis. The articles were exported from WoS to Rstudio (v.1.4.1717) for data analysis. The analysis indicates that 1258 authors were involved in manure management-related research with an author-per-document ratio of 4.4 and a collaboration index of 4.5. Details of the main information concerning the data are shown in Table 1.

Table 1. Main information about the data.

Description	**Results**
Timespan	2010:2021
Sources (Journals, Books, etc)	150
Documents	286
Average years from publication	5.77
Average citations per document	16.1

Description	Results
Average citations per year per doc	2.281
References	11560
DOCUMENT TYPES	
Article	252
article; early access	4
article; proceedings paper	2
book review	1
editorial material	3
meeting abstract	9
Review	15
DOCUMENT CONTENTS	
Keywords Plus (ID)	927
Author's Keywords (DE)	867
AUTHORS	
Authors	1258
Author Appearances	1460
Authors of single-authored documents	8
Authors of multi-authored documents	1250
AUTHORS COLLABORATION	
Single-authored documents	8
Documents per Author	0.227
Authors per Document	4.4
Co-Authors per Documents	5.1
Collaboration Index	4.5

Further analysis shows that the publication trend was unstable in the last decade with the highest research output of 35 articles in the year 2017 representing 12.2% of total production (Fig. 1). Deviations in the number of research papers in a specific field is a significant indicator of developmental trend (Mao *et al.*, 2020). About 32.1% of the 286 articles were published between 2010 and 2014 whereas 194 articles were produced from 2015 to 2021. Fluctuation in citation patterns was observed over the years with a maximum average total citation in 2015, followed by 2020. The lowest citation was observed in 2021. Numerous factors impact the citation of a research article. Such factors include the year of publication or accessibility of the published article by other researchers in the subject area. It is believed that newly published articles have fewer citations than old ones (Aksnes *et al.*, 2019). Similarly, articles published in open access are more cited than those in paid access because open-access articles are more easily available to scholars. However, citations of an article do not determine the quality of the article.

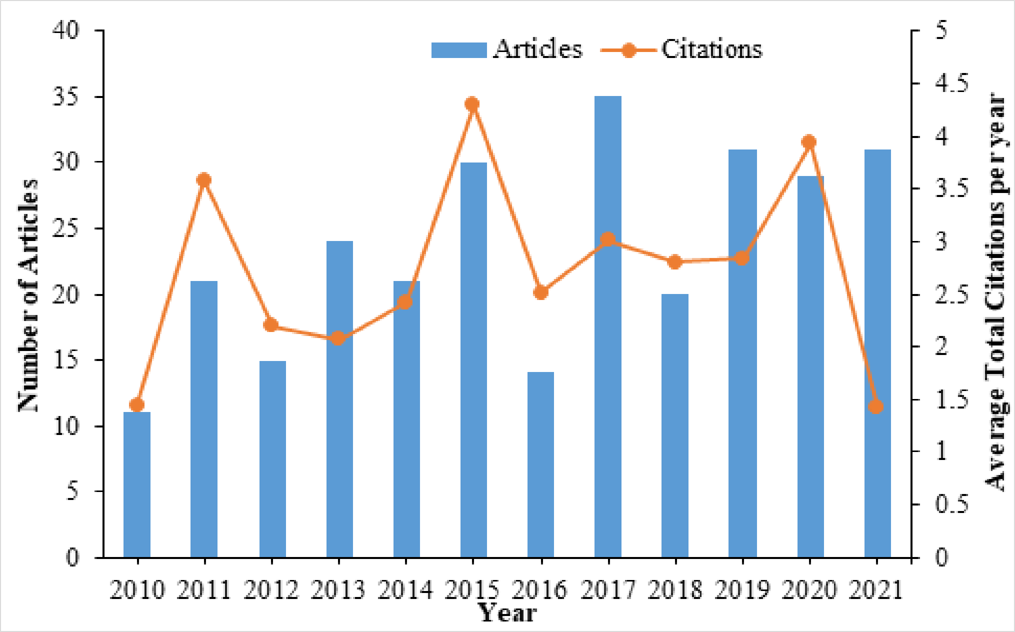

Fig. 1. Annual scientific production on manure management-related research from 2010 to 2021.

In addition, most of the articles are published in high-impact journals such as the Journal of cleaner production, the science of total environment, agronomy journal, journal of environmental quality, communication in soil science and plant analysis, among others. The Journal of Cleaner Production was the most relevant source with 15 published articles, a total citation index of 468 and an H index of 10. The most relevant authors are Czymmek, K.J., Ketterings, Q.M., and Sommer, S.G. with six articles each. Meanwhile, Sommer, S.G. has the highest H index of 6 while Chadwick, D has the maximum total citation (TC) index of 664 followed by Sommer, S.G. with a TC index of 578. The most globally cited document is “Manure management: Implications for greenhouse gas emissions” authored by Chadwick Dave et al., published by Animal Feed Science and Technology in 2011 with a global citation of 330. In terms of country, the United States of America is the most cited country with 209 publications and 1126 citations followed by China with 99 publications and 537 citations. South Africa has the highest publication (n = 10) in Africa, followed by Nigeria (n = 6), Ethiopia (n = 5), Uganda (n = 5), and Kenya (n = 4). This is an indication that more research is needed in manure management in Africa.

The full counting method in VOS viewer software was used to analyze the co-occurrence of author keywords that returns 867 keywords. The minimum number of occurrences per keyword was set as 5, and only 21 items meet the threshold. Only 20 of the 21 items are connected (Fig. 2b). The total strength of each of the co-occurrence links with other keywords was calculated. The 20 keywords were classified into four clusters. Cluster 1(8 items), Cluster 2(5 items), Cluster 3 (4 items), and Cluster 4 (3 items). The Co-occurrence Network and Word Cloud based on the most used keywords among authors noted the term “manure management” was the most used keyword among authors, with 36 occurrences and 24 total link strength, followed by “manure” with 18 occurrences and 22 total kink strength, “anaerobic digestion” with 15 occurrences and 12 total link strength, and others. (Fig. 2).

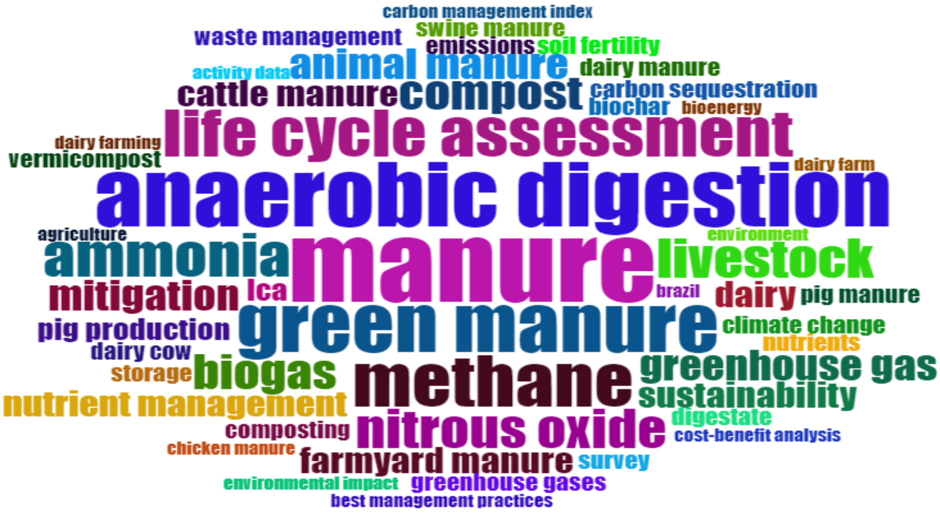

Fig. 2a. Word Cloud showing prominent keywords.

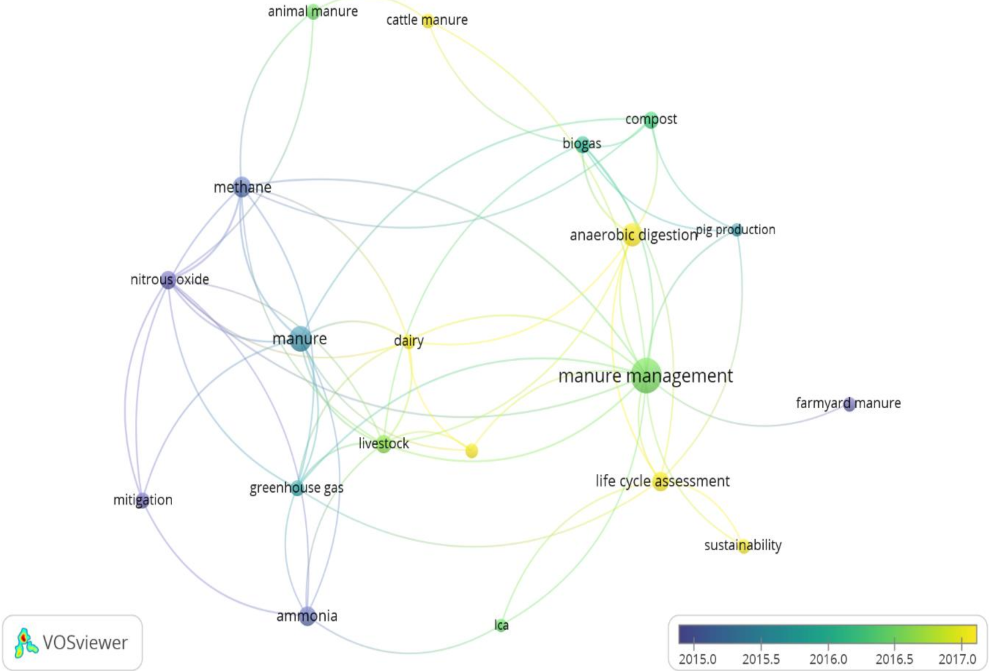

Fig.. 2b. Co-occurrence Network of the most used keywords.

III. ANIMAL MANURE-RISK

3.1. *Impact of Animal Manure on Human Health*

Animal manure is classified as a decomposable product that originates along the value chain of livestock production particularly products of metabolism (both liquid and solid manure). It is an important nutrient pool for improving soil fertility, and crop yield while contributing as a major source of pollutants to air, water and soil (Diacono and Montemurro, 2011). Manure is a major substrate upon which microorganisms feed especially during the process of decomposition and nutrient cycling. Therefore, it is a major storehouse of a different array of microorganisms ranging from bacteria, fungi, and viruses to protozoa. Microbial pathogen abundance and diversity associated with animal manure varies with the species of animal, feed and feeding methods, disposal method and environmental factors such as soil temperature, pH and permeability (Alegbeleye and Sant'Ana, 2020, Bicudo and Goyal, 2003). Other factors include handling and treatment of manure, time of the year, presence or absence of plants, active microbial movement, microbial surface properties and soil water content. Varying disease-causing organisms such as bacterial, viral, fungal, and parasitic enteric pathogen which is zoonotic (infectious to humans) affect livestock during their lifecycle; thereby making the pool of animal waste a broad range of pathogens (Greger and Koneswaran, 2010). Release of animal manure into the environment either through heavy rainfall leads to seepages, runoff and contamination of surface and underground water or direct application to crops on the field poses a threat to soil, air, water, plant, human and animal health.

In recent times, studies on animal waste had focused on its bulkiness, nutrient release especially nitrogen and phosphorus, air and water pollution while little emphasis is on the microbial component of manure. Several studies have reported the abundance of microbial pathogens of zoonotic origin with acute gastrointestinal symptoms such as *Salmonella*, *E.coli*, *Campylobacter*, *Cryptosporidium*, etc. in soils, water and unpasteurized horticultural crops especially vegetables (cabbage, cucumber, carrot) following the application of animal manure (Zambrano *et al*., 2014). Other zoonotic pathogens of economic importance are protozoan (*Cryptosporidium parvum*), enteric viruses and bacteria such as *Salmonella* spp, *Escherichia coli* 0157:H7 and *Mycobacterium paratuberculosis*. Several authors reported the ability of zoonotic pathogens from manure to survive in water for three months and in agricultural soils for more than a year (Burkholder *et al*., 2007, McLaughin *et al*., 2012). The major factors that determine the survival of the pathogens after manure application are biotic (native microbial diversity) and abiotic factors such as soil moisture, pH, temperature and nutrient composition of the soil (Avery *et al*., 2012).

The addition of antibiotics such as tetracycline, tylosin, sulfamethazine, amprolium, monensin, virginiamycin, penicillin and nicarbazine is also a common practice in animal production; they act as growth promoters and feed additives (De Liguoro *et al*., 2003). However, the digestion of antibiotics within the gut of animals is incomplete; the remains are passed out with manure which is taken up directly by a human from polluted water and edible plants. Kumar *et al*. (2005) identified some horticultural crops such as green onion, cabbage and corn as those that can absorb antibiotics from manure ranging from trace to toxic, thereby capable of posing health hazards such as allergic reactions and antibiotic resistance in human beings. The buildup of levamisole, florfenicol, enrofloxacin and trimethoprim and other veterinary antibiotics was reported in lettuce, carrot, spinach, cucumber and pepper (Boxall *et al*., 2006, Wu *et al*., 2013).

3.2. *Impact of Animal Manure on Climate Change*

Animal manure is known to be rich in plant nutrients, hence its application as fertilizer for most horticultural crop production. Nevertheless, excessive application of manure is regarded as an environmental pollutant due to the runoff of organic matter, phosphorus, and nitrogen (that contributes to climate change) into the surface water. The direct impact of livestock besides manure includes enteric fermentation and urine excretion (Pitesky *et al*., 2009). Some of the indirect impacts of livestock production are captured in Livestock's Long Shadow (LLS) as described by the Food and Agricultural Organization (FAO). LLS is the universal life cycle assessment (LCA) of livestock's effect on biodiversity, air and water pollution, land use, water depletion, and anthropogenic Green House Gas (GHG) emissions (FAO, 2006, Pitesky *et al*., 2009).

Generally, livestock generates methane (CH_4) as a by-product of digestion through enteric fermentation while nitrous oxide (N_2O) is produced from urine and manure during the process of nitrification/denitrification and soil carbon iv oxide (CO_2) emissions are due to soil carbon dynamics such as mineralization of organic matter and land-use change (FAO, 2003, Gogli *et al*., 2018). Indirect emissions indicate a discharge from manure applied to the soil, CO_2 released during the production of fertilizer, feed components of animal feed, and CO_2 discharged during handling and transportation of chilled livestock products, as well as deforestation, desertification, carbon released from cultivated soil linked with the livestock (IPCC, 2007, Mosier *et al*., 1998). Chauhan and Ghosh, (2014) reported that cattle, buffalo and small ruminants such as sheep and goats contribute significantly to the total methane emission in the agricultural sector. Animal manure comprises degradable material and water, that undergoes decomposition with the aid of microorganisms thereby resulting in CH_4, CO_2 and other steady organic materials. Swamy and Bhattacharya, (2006) reported that the management of manure from animal sources is the basis of methane emission.

IV. IMPROVED MANURE MANAGEMENT

Untreated and improperly managed manure poses a direct impact on agricultural production (crop, soil and water nutrient), the environment (volatile emissions) and the distribution of enteric pathogens which likely exist and survive in fecal matter and eventually contaminate ready-to-eat food (Gutler *et al*., 2018). If properly handled and improved, various methods identified for manure management including dehydration, solid/liquid separation, anaerobic and aerobic lagoons, composting, storage, refining and methane digester may be used to combat these problems.

4.1. *Recent Trends in Manure Management toward Nutrient Stabilization*

Manure storage is an important management variable affecting nutrient stabilization and the efficacy of nutrients restored to the soil (Ndambi *et al*., 2019). In Kenya, storage of manure in open heaps led to 55% Nitrogen (N) loss compared to 20% N loss observed under manure enclosed with a plastic film kept beneath a roof (Ndambi *et al*., 2019). Manure kept in heaps under a roof also had higher N and Phosphorus (P) levels than those stored in open pits (Tittonell *et al*., 2010). A study in Zimbabwe showed that maize yield increased by 104% under soils treated with manure stored in covered pits relative to soils treated with manure stored in open heaps (Ndambi *et al*., 2019). Liquid manure stored in a smaller surface area has also been indicated to considerably1 reduce N losses (Dadrasnia *et al*., 2021). Thus, manure should be stored under shade or covered to minimize continuous exposure to high temperatures and rainfall, reduce evaporation losses and subsequent N losses, thereby lessening nutrient shortfall owning to leaching (Ndambi *et al*., 2019, Dadrasnia *et al*., 2021). It has also been shown that N and other nutrient losses may be reduced through shorter storage duration and rapid integration of manure into the soil (Dadrasnia *et al*., 2021).

The composting of animal manure is a valuable management approach to produce a stabilized fertilizer that is spread onto land with a reduction in volume and moisture, little or no odor, and nitrates, ease of storage and transport, and microbial stabilization (Font-Palma, 2019). Composting implies the mineralization and incomplete humification of organic matter resulting in stabilized finished products (Huygens *et al*., 2020). In recent times, the amendment of manure compost with biochar has become valuable for enhancing organic matter degradation and nutrient stabilization. Biochar speed up organic matter degradation by improving the aeration of the compost material, stimulating microbial activity, and adsorbing compounds (e.g., NH_3, NH_4^+,

H_2S, SO_4^{2-}) that slow down the degradation process (Godlewska *et al*., 2017). It was observed that the addition of 10% and 15% wheat straw biochar to piggery manure hastened compost maturation and humification within 63 days of composting (Zhang *et al*., 2016).

Furthermore, the amendment of chicken manure compost with 10% bamboo biochar resulted in a lower C : N ratio (which reflects the degree of compost maturation) than those without biochar amendment (Liu *et al*., 2017). The enhanced degradation by biochar during composting helps nutrient stabilization and reduces storage time thereby avoiding nutrient runoff/leaching to water bodies and irrigation reservoirs. Li *et al.* (2021) varied moisture content (from 45-61%) while composting chicken manure under functional microbial inoculation and found that the heap heating, nutrients conversion and transformation, including the nutrient status of the compost, was best at 53% optimum moisture content. These authors opined that the optimum moisture content also contributed to better product safety (11.43-23.58% higher seed germination than others), prevention of leaching and possible secondary pollution. The mixture of poultry manure with alum (Aluminum Sulfate) resulted in a decrease in animal-house NH_3 level, precipitation of soluble phosphorus, and reduction in phosphorus, heavy-metals run-off and litter moisture (Malomo *et al*., 2018). Compared to untreated manure, the application of 1.5% alum to manure led to a higher N level (Malomo *et al*., 2014). Bautista *et al.* (2011) also reported a 92% reduction in NH_3 emission and a subsequent increase in the N concentration of piggery compost after treatment with alum. Higher N concentration was observed in alum-treated manure as a result of reduced N loss due to NH_3 volatilization compared to untreated manure (Malomo *et al*., 2018).

Anaerobic digestion (AD) is another manure management option whereby the residual material/digestate generated could be recycled while using manure nutrients in a sanitized and stabilized form (Moller, 2015). During manure treatment, AD converts part of the organic N into plant-available N (NH_4^+), thereby increasing N use efficiency and offering target-oriented N application in time and space (Huygens *et al*., 2020). Results showed that the N accessibility in digestate improved by 10-25% compared to manure without treatment after AD (Moller and Muller 2012). This is an indication that the use of digestate derived from AD of manure can improve fertilizer efficiency, reduce chemical N fertilizer demand/use and nitrate fertilizer leaching.

4.2. *Recent Trends in Manure Management toward Pathogen Reduction*

Animal manures, an effective and reliable fertilizer source in crop production carry many pathogens (Harris *et al*., 2013). It is important to manage animal manure towards the elimination of pathogens and lessen the consumption of contaminated fresh produce. Various treatment methods have been identified for this purpose which includes anaerobic (Mesophilic and thermophilic) digestion, drying, composting, centrifugation and multicomponent systems (Gutler *et al*., 2018).

The use of AD for manure treatment led to a significant decrease in the populations of aerobic bacteria, actinomycetes, and fungi (Gutler *et al*., 2018). With dairy and swine manure slurry, ammonia and humus substances produced during AD contribute to the impairment of zoospore propagation by the plant pathogen *Phytophthora capsici* in these systems (Cao *et al*., 2013). This inactivation mechanism indicates the termination of spore-forming foodborne pathogens. The survival of pathogenic bacteria depends on the temperature (mesophilic 30-38 °C or thermophilic 50-55 °C) and hydraulic retention time during AD (Costa *et al*., 2017). Previous studies have indicated a reduction in biomass odors and pathogen contents after mesophilic AD of manure (Bedoic *et al*., 2019, Riva *et al*., 2016). A study by Rajagopal *et al*. (2019) also reported about 90-100%

removal of pathogens such as E. coli, streptococcus, total gram-negative bacterial growth, *Salmonella* and *Klebsiella* after cow manure was treated with dry AD at a lower temperature of 28 °C.

Appropriately composted feedstocks that enhance C: N ratios, water contents and temperature can reduce bacterial foodborne pathogens existing in livestock manures to levels recommended by regulatory agencies and this can be used as a biological soil amendment for fruits and vegetable cultivation (Gutler *et al*., 2018). Macias-Corral *et al.* (2019) examined dairy manure compost with varying C: N ratios of 21 (100% manure), 22 (25% maize straw + 75% manure), 27 (50% maize straw + 50% manure) and 38 (75% maize straw + 25% manure), and concluded that the treatment mixture with C: N ratio of 22 best-eliminated *Salmonella* species, fecal coliforms, and helminth eggs. A recent study by Esperón *et al.* (2020) also revealed that composting poultry manure for 10 weeks reduced pathogenic bacteria such as *Campylobacter coli* or commensal bacteria such as *Escherichia coli*.

The amendment of different manure compost with black soldier fly larvae *Hermetia illucens* L. (*Diptera: Stratiomyidae*) led to about 90-92% of pathogenic bacteria (*Bacillus*, *Salmonella*, *Vibrio* and *Enterococcus* spp.) reduction in poultry and cow manure and 86-88% decrease in pig manure while they were found in abundance in the untreated compost (Awasthi *et al*., 2020). Liu *et al.* (2017) examined the influence of centrifugation speed on the elimination of pathogens from dairy manure. The results showed that a high centrifugation speed of 6000 x g considerably reduced manure solids and bacterial indicator levels. They suggested that higher centrifugation speed and longer retention time could further enhance pathogen reduction during large-scale manure solid/liquid separation.

4.3. R*ecent Trends in Manure Management toward Reduction of Greenhouse Gas and Volatile Organic Emissions*

Animal manures have huge N and organic matter that contributes largely to universal NH_3 and GHGs release (Wang *et al*., 2016). Gaseous emissions from manure management may occur during in-house handling, outdoor storage and treatment, and land application (Chadwick *et al*., 2011). As NH_3, CH_4 and N_2O emissions arise out of physical, chemical and microbiological processes, these discharges are affected by manure characteristics, oxygen availability, temperature, exchange between the release of CH_4 and N_2O, including collaborations between N_2O and NH_3 (Wang *et al*., 2016). It is therefore important to understand and adopt the manure management practices that best mitigate GHG emissions.

The use of straw in the covering of stored manure led to the reduction in the discharge of NH_3 by establishing an anaerobic zone above storage areas where nitrification can occur (Dennehy *et al*., 2017). CH_4 and NH_3 production decrease while N_2O discharge increase mainly in areas with warm air conditions (Dennehy *et al*., 2017, Petersen *et al*., 2013). The decrease in CH_4 emissions after covering is due to the oxidation of CH_4 at the surface of the manure, while increased nitrification of NH_3 results in increased emissions of N_2O from the nitrification-denitrification cycle (Dennehy *et al*., 2017). Acidification of manure during storage or composting has also been indicated to control NH_3 and CH_4 emissions (Cocolo *et al*., 2016). NH_3 emission is prevented during acidification by remaining in the soluble NH_4-N form. Proper management involving active aeration during composting can greatly reduce GHG emissions compared to unmanaged storage (Dennehy *et al*., 2017).

The application of biochar to compost can reduce the formation of anaerobic pockets leading to the reduction of CH_4 emission (Chen *et al.*, 2017). For example, about 15.5%-26.1% reduction in CH_4 emissions was recorded after amending manure compost with biochar (Chen *et al.*, 2017). The addition of soft and hardwood biochar to cattle slurry and hen manure compost at different airflow rates resulted in about 27%-32% reduction in total GHG emission (CO_2 equivalent) (Chowdhury *et al.*, 2014). A reduction in CH_4 emissions was also observed after treating animal manure with granular biochar (He *et al.*, 2019) and 10% bamboo biochar (Liu *et al.*, 2017). Biochars aid the mitigation of GHG emissions by limiting the development of an anaerobic environment and thus ensuring aerobic conditions during manure management. During field application, the amendment of manure with nitrification inhibitors (dicyandiamide, 3, 4-dimethyl pyrazole phosphate and nitrapyrin) led to 70%, 50% and 88% reduction in N_2O emissions (Chadwick *et al.*, 2011, Vanderzagg *et al.*, 2011, Minet *et al.*, 2016). Nitrification inhibitors were performed based on the climate and soil type (Gilsanz *et al.*, 2016), and lower efficiency was detected in predominantly anaerobic condition sites (Vanderzaag *et al.*, 2011). Nitrification inhibitors are often added to manure before field application to prevent NH_4^+ oxidation to NO_3^-, thus breaking the + nitrification/denitrification cycle and significantly reducing overall N_2O emissions (Dennehy *et al.*, 2017). However, the use of nitrification inhibitors on manure during field application is limited due to the high cost and application rate needed for some inhibitors (dicyandiamide and 3,4-dimethyl pyrazole phosphate) as well as health and safety aspects associated with others (nitrarpyin) (Vanderzaag *et al.*, 2011).

Manure application methods may considerably impact the level of greenhouse gas emissions. For example, the injection of piggery manure into the soil led to a significantly higher N_2O emission compared to those applied on the surface (Velthof and Mosquera, 2011). This was possible because the injection is known to upsurge the quantity of mineral N going into the soil and subsequently the amount available for conversion to N_2O. Furthermore, the injection may lead to an upsurge in the occurrence of anoxic conditions within the soil which promotes denitrification (Chadwick *et al.*, 2011, Montes *et al.*, 2013). However, Lovanh *et al.* (2010) observed higher N_2O and CH_4 emissions under surface manure application compared to row injection, while Rodhe *et al.* (2012) indicated that the application method had no considerable effect on N_2O emissions. Site-specific conditions such as ambient temperature, soil type and changes in manure composition might have largely contributed to the inconsistent results observed under those application types (Montes *et al.*, 2013). Dennehy *et al.* (2017) postulated that the use of injectors and similar application methods will lessen direct N_2O emissions if the applied N loading rates are reduced to account for the higher levels of N entering soils from injection and incorporation of manures.

In addition to nutrient utilization and waste reduction, AD has also been shown to mitigate GHG emissions in manure management (Zhang *et al.*, 2019). During AD of liquid piggery manure, proper consideration of biogas use and reduced emissions from manure storage led to a reduction of between 15 and 20 kg CO_2 eq t^{-1} piggery manure (De Vries *et al.*, 2013, Xie, 2012). The previous result showed that the GHG emissions from stored manure treated with AD were half of the piggery manure (untreated) (Amon *et al.*, 2006). This is because the AD system can remove between 40% - 80% of the volatile solids from piggery manure (Dennehy *et al.*, 2017). Recent reports also indicated lower CH_4 emissions from digestate compared to raw manure during storage (Holly *et al.*, 2017, Huygens *et al.*, 2020). Thus, the AD digestion of manure before storage may be an effective approach to mitigating GHG discharges during storage. However, the amount of GHG emission to be mitigated during AD is a function of the atmospheric temperature, which is an important factor in ascertaining the GHG production from manure storage (Yao *et al.*, 2020, Zhang *et al.*, 2019).

The N_2O, CH_4 and NH_3 emissions will be maintained at a low level so far the storage temperatures of digestate remained less than 15ºC (Wang *et al*., 2017). A significant increase in N_2O and CH_4 emissions is directly related to a higher temperature. N_2O emission has also been observed to be lower in field plots treated with digestate than in untreated manure. This is probably because, compared to the untreated manure, the digestate that was applied has reduced volatile solid content (due to AD) that can lower microbial activity thereby reducing nitrification and denitrification rate (Montes *et al*., 2013). A review by Yao *et al.* (2020) indicated that 2839.6, 108,280.3, 8891.7, 14,993.6 and 30,675.5 Gg of CO_2 eq. emissions from buffalo, breeding swine, dairy cattle, market swine, and other cattle manures, respectively, will be avoided each year if 50% of manures could be managed using AD technology. The total emission of 165,680.9 Gg of CO_2 eq. per year will consequently be avoided, which is about one-quarter of Canada's annual GHG emissions in 2030. Pig manure contributes 18% of the entire global GHG emissions from livestock production (Philippe and Nicks, 2015), it contributes 44%, 32% and 76% of the national NH_3, N_2O and CH_4 emissions, respectively, in China's livestock manures (Wang *et al*., 2016). Compared to ruminant manures (Cattle manure), piggery manure has a higher capacity to produce CH_4 gases because they are monogastric animals and the manure generated typically contains a higher percentage of biodegradable carbon. Hence, it is crucial to understand the different piggery manure management methods to improve the mitigation of GHG emissions. Wang *et al.* (2017) postulated that 65% of GHG and 78% of NH_3 emissions could be reduced if swine manure management is changed from liquid systems to solid-liquid separation systems, combined with mitigation measures.

V. CONCLUSION

This study presents the bibliometric analysis of published articles on manure management between 2010 and 2021, the impact of animal manure on human health and climate change, as well as recent trends in manure management towards nutrient stabilization, pathogen reduction, decrease in greenhouse gas and volatile organic emissions. The bibliometric analysis of published work between 2010 and 2021 revealed most research work is focused on the impact of manure on health, carried out in developed nations like USA and China. Much work is needed on the impact of manure on climate change, especially in developing nations such as Africa. The appropriate strategy for manure management should be based on available resources of human and capital for global health. This review could support the global effort concerning sustainable agricultural waste management by inspiring new thoughts and directions in animal manure management, as well as promoting the application of fresh insight in animal manure research to improve manure management strategies.

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AUTHOR CONTRIBUTION STATEMENT

Oladunni Ayoola Akinpelu: Conceptualization, Methodology. Olaleye oladiran: Writing-Initial draft preparation. Adewole Tomiwa Adetunji: Writing-Reviewing and Editing

DECLARATION OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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