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Review Article

Vermicomposting: Tool for Sustainable Ruminant Manure Management

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Ruminants are important sources of meat and milk. Their production is associated with manure excretion. Estimates of over 3,900,000 million metric tonnes of manure are produced daily from ruminants worldwide. Storage and spread of this waste on land pose health risks and environmental problems. Efficient and sustainable way of handling ruminant manure is required. Composting and vermicomposting are considered two of the best techniques for solid biomass waste management. This paper presents vermicomposting as an effective tool for ruminant manure management. Vermicomposting is a mesophilic biooxidation and stabilisation process of organic materials that involves the joint action of earthworm and microorganism. Compared with composting, vermicomposting has higher rate of stabilisation and it is greatly modifying its physical and biochemical properties, with low C : N ratio and homogenous end product. It is also costeffective and ecofriendly waste management. Due to its innate biological, biochemical and physicochemical properties, vermicomposting can be used to promote sustainable ruminant manure management. Vermicomposts are excellent sources of biofertiliser and their addition improves the physiochemical and biological properties of agricultural soils. In addition, earthworms from the vermicomposting can be used as source of protein to fishes and monogastric animals. Vermicompost can also be used as raw materials for bioindustries.

1. Introduction

Nutrients losses from animal production in the form of manure are inevitable. Excessive animal waste results from an intensive ruminant production (management), high stocking density, or from feeding nutrients more than required by the animals [1]. The nutrients loss and waste products may exceed the carrying capacity of an area and become detrimental to the environment. Poor manure management contributes to pollution and eutrophication of surfaces water, ground water, and coastal marine ecosystem. It contributes to air pollution through emissions of odour, ammonia, methane and nitrous oxide, and it also contributes to soil pollution through the accumulation of heavy metals. These pollution and eutrophication effects subsequently lead to loss of human health, biodiversity, climate change, acidification, and ecosystem degradation [2]. Ruminant livestock has the highest contribution to these GHG emissions among livestock [3]. The sources of these GHG emissions and other pollutants from ruminants are respiration, enteric fermentation and manure. Nutrients losses due to ruminant production are either from enteric fermentation or manure that is influence by nature and composition of feed [4]. Factors such as the type and profile of nutrients in the feed, level of feed intake, rate of digesta passage, feed preservation methods, physical processing, chemical, and or biological treatment have direct effect on animal productivity as well as faecal and urine output [5, 6].

Ruminant manure is a valuable resource as a soil fertiliser, providing both macro, and micronutrients required for the plant growth, and is a low cost alternative to mineral fertiliser [7]. Nevertheless, only a fraction of the nutrients excreted by livestock manure is properly collected and managed as manure [2] and difficulties are encountered in disposing excreta from livestock produced in large feed lots [8]. However, unmanaged and over-production of the manure (from intensive production) have led to inappropriate and indiscriminate application, resulting in overfertilisation, soil toxicity, dispersal of pathogens, odour, water pollution, and increase in greenhouse gas emission [9]. Therefore, livestock

Table 1: Distribution of ruminant livestock (% of global total) by region 2010.

	Buffaloes	Cattle	Goat	Sheep
Africa	2.06	19.78	34.17	27.75
Asia	97.14	33.06	59.29	42.18
Europe	0.20	8.71	1.88	12.14
Latin America	0.60	28.37	3.78	7.99
North America	—	7.47	0.34	0.60
Oceania	—	2.61	0.54	9.34
World total	194, 152, 560	1, 430, 101, 625	909, 691, 076	1, 077, 762, 456

Source: FAOSTAT, 2013 [11].

farms will need an improved manure management strategy [2].

Composting and vermicomposting are two of the best known processes for the biological stabilisation of solid waste [7]. However, composting reduces agronomic value of compost and contributes to greenhouse gas emission due to nutrients losses during compost making. Moreover, composting requires human labour or fuel in order to turn the compost heap to ensure aeration [10]. On the other hand, earthworm in vermicomposting process serve as an agent for turning, fragmentation, and aeration of the manure; therefore, it drastically increase the rate of microbial activities [9].

2. Ruminant Global Distribution and Manure Production

In 2010, world's ruminant population was about 3.6 billion, of which 5.38%, 39.59%, 25.19%, and 29.84% were for buffaloes, cattle, goats and sheep, respectively [11]. The relative distribution of the number of ruminant animals in different parts of the world according to FAOSTAT [11] was shown in Table 1. However, there are large differences between regions in the share of animal numbers and production. For example, Europe has only 8.71% of the total cattle but supplies 17.10% and 34.70% of global cow meat and milk respectively. On the other hand, Africa has 20% of the global cattle but produces 9.74% and 5.30% of world's cow meat, and milk, respectively, indicating different production systems.

Livestock excreta (ruminant inclusive) have not been treated with the importance they deserve; hence, estimates of their global amount excreted are highly uncertain [2, 8, 12]. However, estimates of manure dry matter (DM) excretion are useful for designing manure treatment and handling technologies or for the development of future manure treatment technologies and for nutrient management [13]. Attempts had been made to predict an estimate of nutrient excretion from ruminant and most of the works were done on dairy and beef cattle [8, 13–16]. It had been assumed that under free access to feed, ruminants excrete a constant amount of faeces per unit live (W) or metabolic ($W^{0.75}$) weight [17]. An equation to estimate potential faecal dry matter (DM) output (F, g/day) of cattle had been developed by Konandreas and Anderson [18] as follows:

$$F = fW^{0.75}, \tag{1}$$

where f (g DM/kg $W^{0.75}$) is a constant that depends on the physiological state of the animals.

The values of 42, 45, and 49 were estimated for dry, pregnant, and lactating cows, respectively. It is also suggested that these estimates could be used for feeds in a range of digestibilities from 42 to 65%. Fernández-Rivera et al. [17] considered wide range of digestibilities from 24.3 to 84.1% and an average daily faecal excretion/DM was determine as 2.383 Kg for cattle, 0.345 Kg for sheep, and 0.197 Kg for goat. From these, it can be assumed that an average of 3,407,932; 371,828, and 179,209 metric tonnes of faecal output/DM are excreted from cattle, sheep, and goat daily in the world. Strong relationship exists between apparent digestibility, feed intake, and faecal output. An increase in ruminant nutrients digestibility result in a decrease to faecal output while, an increase in feed intake increases faecal output [17]. Hoffman et al. [19], reported that heifers limit fed at 80 and 90% of ad libitum intake excreted 0.86 and 0.36 Kg/daily less dry matter, respectively, as compared with control diet with improved feed efficiency.

Based on production system, Sheldrick et al. [8] recognised three types of excreta as (i) from livestock grazing on pasture or rangeland, (ii) from livestock grazing on crop residues in the field, and (iii) from housed livestock. It's excreta from housed livestock can be collected, stored, and used at appropriate time and location. Ruminant manure from animal house consists of faeces, urine, bedding materials, split feed, split drinking water, and water used for washing the pen and it will be collected below slatted floor as slurries. When livestock are tied, the excretions are separated into solid manure, known as farm yard manure [12].

3. Ruminant Manure Characteristics

The amount and nutrient content of faeces excreted are highly variable and depend on types of animals, animal weight, diets, livestock production systems, and apparent digestibility [20, 21]. Other factors include dietary concentrations of crude protein, neutral detergent fibre, and nutrients intake [13]. Nutrients found in the manure or in compound emitted to the air and water originate from fraction of the feed which is not retained by the animals [22]. The nutrients of most concern are nitrogen (N), phosphorous (P), and potassium (K). Ruminant manure contributes 75, 66.4, and 83.6% N, P, and K, respectively, from the world total livestock excreta [8].

Manure N is partitioned between organic and ammonium N. Organic N is assumed to come primarily from faeces [15]. The type and amount of crude protein (CP) consumed by ruminant affect total N excretions and the relative amount of N excreted in faeces and urine [6]. Lowering the CP content of diet will decrease the amount of N excreted by animal and vice versa. Somda et al. [20] reported that total amount and proportion of nutrients excreted in faeces and urine varied with the lignin : neutral detergent fibre (NDF), lignin : N, and polyphenol : N ratios of the diet. An increase in dietary fermentable energy content at a similar N intake level increases N excretion in the faeces with decline of N excreted in urine [23]. Tannins and polyphenols also shift N excretion from urine to faeces and from soluble to insoluble N form in faeces [6].

Ruminants excrete P mainly in faeces, which consist of unabsorbed dietary P and endogenous (from saliva, digestive juices, Intestinal) and the remaining source is through urine. Faecal endogenous P is the main pathway of P excretion (up to 85%) and the remaining is mainly unabsorbed dietary P [24]. Total P excretion in faeces depends largely on P intake. The ratio of endogenous faecal P to total faecal P is highly variable depending on the age, diet, and physiological condition of the animal [25]. Endogenous P losses becomes the predominant source of faecal P (70–80%) on diet low in P, as P intakes increase the ability of faecal endogenous excretion become saturated and most of any excess P is excreted in urine [26]. More than 90% of the heavy metals consumed by ruminant in the feed are excreted in the faeces or urine [2, 22].

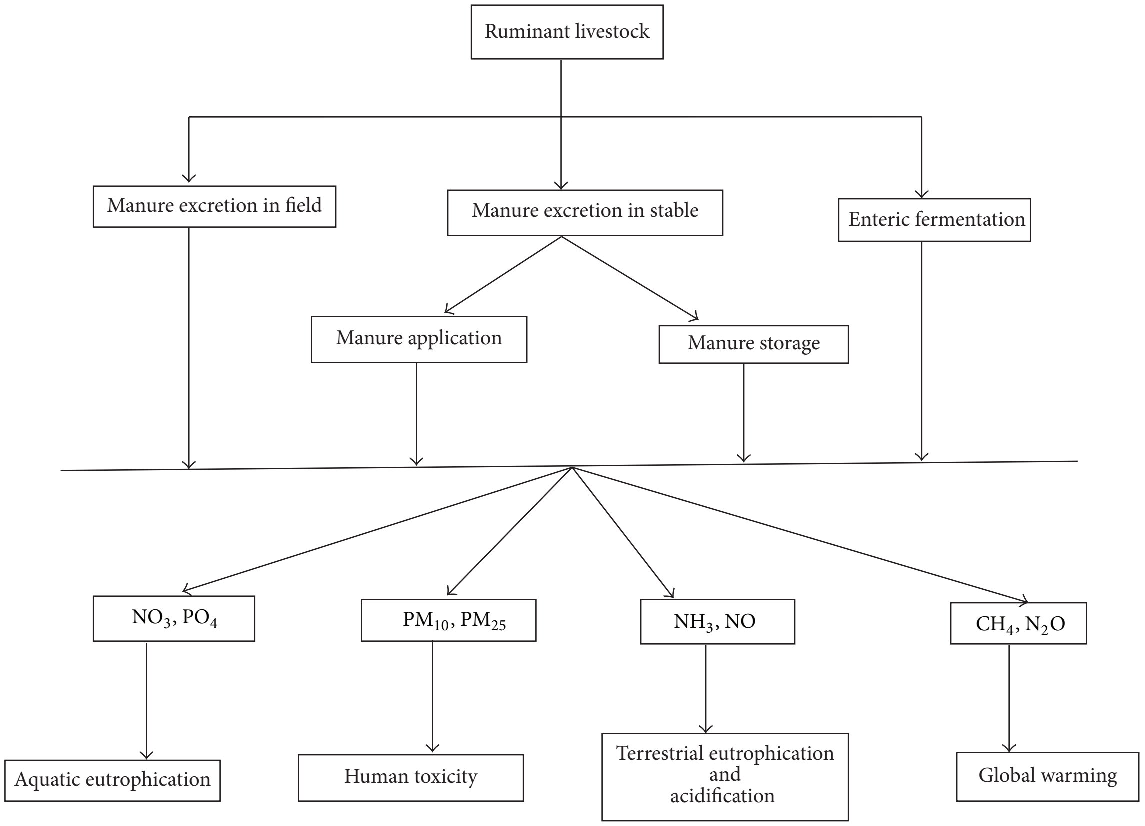
4. Impact of Ruminant Manure and Its Management on the Environment

Losses from ruminant manure management systems roughly decrease in order of C, N $>$ S $>$ K $\geq$ Na $\geq$ Cl $\geq$ B $>$ P $\geq$ Ca $\geq$ Mg $\geq$ Fe $\geq$ Mn $\geq$ Cu $\geq$ Zn $\geq$ Mo $\geq$ Co $\geq$ Se $\geq$ Ni. This order is related to the reactivity, speciation, solubility, and fugacity of the nutrient element species. The double mobility of C, N, and S in soluble waterborne compounds as well as in gases makes their cycling and loss pathways much faster and more complex than those of the mineral elements [27]. Current environmental concerns relate mainly to gaseous emissions of ammonia (NH_3), nitrous oxide (N_2O), and methane (CH_4) from manure management system to atmosphere, to the leaching of nitrate, (NO_3^-) to groundwater, and to nitrogen (N) both organic and inorganically bound N species and P particulate losses from manure management to surface water [2]. Nitrogen is released in gaseous forms (mainly NH_3, N_2, N_2O, and NO), in dissolved forms as inorganic and organic N (NO_3^-, NH_4^+, DON) and as particulate matter via run off. Carbon is released from manure in gaseous form forms mainly CO_2 and CH_4, in dissolved forms as organic and inorganic C (ΣHCO_3, DOC) and as particulate matter (Via run-off). On the other hand sulphur is lost via volatilisation of sulphides (H_2S) and sulphur dioxides (SO_2) and the leaching of sulphate (SO_4^{2-}) and particulate matter [27] (Figure 1).

5. Manure Management

Ruminant manure collected in housing systems has to be stored for some time inside or outside the housing system until timely spread of the manure on the field, that is, during the growing season when the crop will be able to utilize the plant nutrients [28]. Traditionally ruminant manure is normally spread in the farm without any treatment [10]. Farmers applied these organic fertilisers for the long-term benefit of their soils. Manure helps in stabilization of soil aggregates preventing erosion; it improves soil structure promoting moisture retention and it even may correct drainage problems in wet areas [29]. Losses or emissions in the form of volatilization, leakage, run-off, and dumping occur during storage and application of the manure [30]. When applied in excess to the land requirement, it can lead to environmental pollution. These include overfertilisation of soil, soil toxicity, dispersal of pathogens and weed seeds, odour, water pollution, and increase in greenhouse gas emission and may pose health risk [9]. However, ruminant manure is stored for a month or more before being applied into the soil [12]. Apart from being less effective compared with mineral fertiliser, slurry poses several problems during storage, likewise during and after its application. As conditions in the slurry are anaerobic, this means that CH_4 and CO_2 are produced as end products. After application, NH_3 emissions increase with an increase in slurry dry matter content. Environmentally friendly slurry application requires the slurry to be evenly applied near or under the surface [31]. Generally, manure storage contributes to the atmospheric pool of gases such as ammonia, nitrous oxide, and methane [32]. NH_3 and greenhouse gases losses result from microbiological, chemical, and physical processes. The environmental and health risk imposed by ruminant manure mentioned earlier is due to its nonstabilisation. Stabilisation is degree of decomposition of a waste substance, which is reflected by decrease in level of microbial biomass activity and concentrations of labile compounds [7, 33]. Stabilisation reduces the environmental problems associated with manure management by transforming it into a safer and more stabilised material suitable for application to soil [33].

Composting is a widely used method for disposal of animal waste [34]. Farmers used it for various objectives which includes reducing the mass of manure before spreading, homogenizing the manure, destroying pathogens and weed seeds, deodorizing the manure, or making it into a saleable product with the aim of returning it to agricultural land [30, 35]. Composting is continuous aerobic degradation of organic materials by microorganism into humus-like substances. Composting is one of the best known processes for the biological stabilisation of solid waste [7]. Composting is a microbial aerobic decomposition process with the formation of stabilised and matured organic materials. Efficient composting requires the control of several factors in order to obtain a quality agricultural product. It have been grouped into two, those depending on the composting mix such as nutrients balance, pH, particle size, porosity, and moisture, and those depend on the process management such as oxygen concentration, temperature, and water content. Therefore, composting animal manure should be seen as technology



Source: Havlikova et al., 2008 with modification

Figure 1: It shows associated nutrients loss in ruminant production and manure management.

which adds value and produces a high quality product for multiple agricultural uses. According to Peigné and Girardin [36], studies have demonstrated that nutrients are lost during the composting operation and may induce environmental problems. Losses are generated in many ways: as ammonia volatilisation, as nitrous oxide and methane emissions, or as nutrients leached in drainage water. Nutrient losses can be up to 62% (C), 42% (N), and 6.5% (K and Na) and less than 6% (C and Mg) and 2% (P), and these are related to the initial manure content [37] and compost management employed. The product of composting sometime is heterogeneous and the process require long period of time to be completed [38]. Air and water are the main environmental components that are affected by composting pollution. Nutrient and salt loss during composting resulted in reduced electrical conductivity of the composted manure. In addition to energy loss due to labour or fuel required to turn the compost heap, these reduce agronomic value of compost and contribute to greenhouse gas emission [10, 37].

6. Vermicomposting as an Effective Tool in Ruminant Manure Management

Vermicomposting is a mesophilic biooxidation and stabilisation process of organic materials that involve the joint action of earthworm and microorganism. This increases the rate of the decomposition process by accelerating the stabilisation of organic matter and greatly modifying its physical and biochemical properties [39]. Microorganisms produce the enzymes that cause biochemical decomposition of organic matter, but earthworms are the crucial drivers as they stimulate and increase biological activity by fragmentation and ingestion of organic matter and this will increase the surface area to be exposed to microorganism [39]. Earthworms act as mechanical blenders and by comminuting the organic matter they modify its physical and chemical status by gradually reducing the C : N ratio and increasing the surface area exposed to microorganism [40]. They also serve as agent of turning and aeration [38].

A Vermicomposting process has two distinguished phases and is (i) an active phase, where the earthworms process the biomass, modifying its physical state and microbial composition. The effect of earthworm on the decomposition of organic matter during vermicomposting processes is due to gut associated processes (GAPs), and it includes the modification that organic waste and microbes undergo during their passage through the gut of earthworm. (ii) A maturation like phase, also known as cast associated processes (CAPs), is marked by the displacement of the earthworm towards fresher layers of undigested waste, where the microbes take over in the decomposition of waste and the effects of earthworm are mainly indirect and derived from GAPs

[7, 9, 39]. Vermicompost is a finely divided, peat-like material with a low C : N ratio, excellent structure, porosity, aeration, drainage, and moisture-holding capacity, and it supplies a suitable mineral balance, improves plant nutrient availability, and could act as complex-nutrient-source granules [9]. Earthworm plays a significant role in processing ruminant manure as it reduces the moisture content, pH, and electrical conductivity compared with composting [41, 42]. These might be attributed to high rate of mineralisation, this can be up to 60% [43], and it brings accumulation of organic acids from microbial metabolism and enhances production of fulvic and humic acids during decomposition [44]. According to Atiyeh et al. [41] carbon dioxide evolution decreases rapidly (44%) one week after the introduction of earthworms, and continued at a lower rate throughout the 17 weeks, 51% reduction as compared to 22% without earthworms, indicating increasing organic matter stability. Vermicomposting enhanced nitrogen mineralisation and increase the rates of conversion of ammonium-nitrogen into nitrate. This will increase the concentration of nitrate-nitrogen to 28% after 17 weeks, while in compost the nitrate-nitrogen concentration will increase by 3%. This suggests that earthworms produced conditions in the manure that favoured nitrification, resulting in rapid conversion of ammonium-nitrogen into nitrates [41]. Comparison of compost and vermicompost showed that vermicompost had significantly lower C : N ratios, and this was due to loss of carbon as CO_2 during bioxidation and production of mucus and nitrogen excrements increase the level of nitrogen which lower the C : N ratio [42, 45]. With regard to lignolysis, Vinceslas-Akpa and Loquet [46] find out that at the beginning of vermicomposting, lignolysis was more efficient compared with composting; however, at the end fraction identified as cellulose increased particularly in the vermicompost, apparently the rate of cellulolysis and lignolysis was slightly faster in the compost. Vermicomposting increases the ash content and accelerates the rate of mineralisation which is essential to make the nutrients available to plant [43]. Ruminant manure vermicompost was found to have the highest total phosphorous compared to other livestock manure vermicomposts [42]. Among the effects of different microorganisms and enzymes contributing to such increased availability of phosphorus, major emphasis may be given to the presence of very high concentration of phosphate-solubilising bacteria in the vermicast [47]. Addition of vermicompost to the soil adds to its mineralogical nutrients and contributes to its biological fertility by adding beneficial microbes to the soil. It favourably affects soil pH, microbial population, and enzyme activities. It also reduces the proportion of water soluble chemicals, which causes possible environmental contamination. All these help in increased production of healthier crops [43, 47].

7. Conclusion

Manure production is an inevitable aspect of ruminant production. Under free access to feed, ruminants excrete a constant amount of faeces per unit liveweight. Millions tonnes of ruminant manure are produced daily; without proper handling management, it results in increase in GHG emission and environmental pollutions. These called for efficient and sustainable way of treating the waste. Composting and vermicomposting are considered as the best option for biomass management. However composting reduces the agronomic value of the products and contributes to environmental pollution, in addition to energy loss due to labour or fuel required to turn the compost heap compared with vermicomposting. Earthworms can break down organic matter very rapidly, resulting in stable, nontoxic vermicomposts with a better structure, microbial content, and available nutrient content than composts. Vermicomposting through the activities of earthworm associated microbes accelerated the process of ruminant manure decomposition and stabilisation and promoted biochemical characteristics that were favourable to plant growth. Vermicomposting is a cost effective and eco-friendly waste management technology and has many advantages over traditional composting.

Conflict of Interests

The authors declared that they have no conflict of interest.

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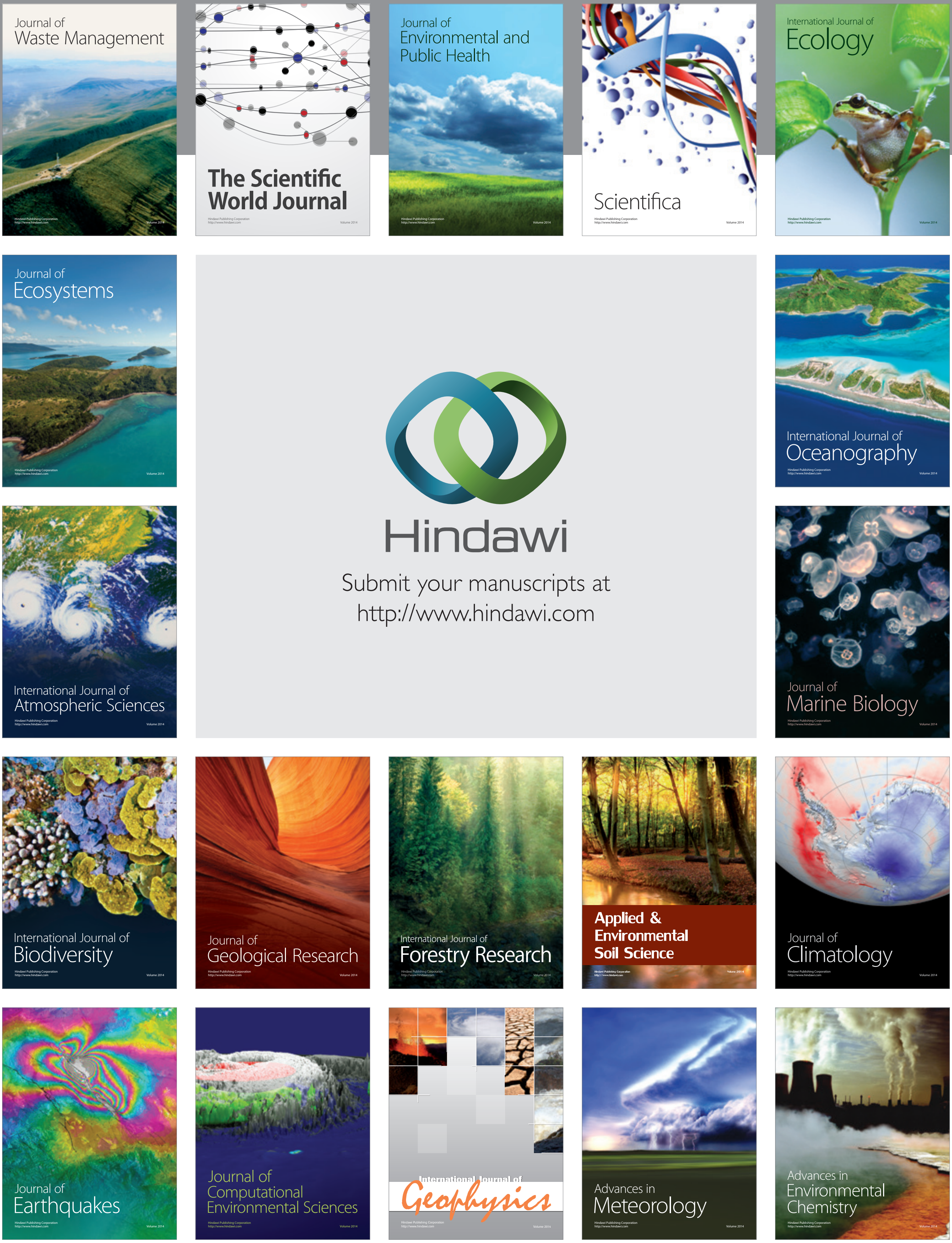
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