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REVIEW

Eco-friendly and modern methods of livestock waste recycling for enhancing farm profitability

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Abstract The livestock waste is major source of noxious gases, harmful pathogens and odor; hence, it has public health and environmental concern. Hence, livestock waste is to be managed properly to mitigate production of these pollutants in order to protect environment. Proper utilization of livestock waste into biogas, compost and vermicompost making can be very useful to increase crop yield and sustainability. The work carried out regarding livestock waste management and value addition in some developed and some developing countries have been reviewed. India and China are the two leading Asian countries using biogas technology. The biogas can be successfully purified and after bottling at 150 bar pressure can be used as CNG cylinders in vehicular and cooking application. The biogas plant of 60 m^3 capacity if used for biogas bottling can save $147/day. The integration of composting and vermicomposting is better compared to either composting or vermicomposting as it requires less time to complete cycle and furthermore, the substrates produced after combined process has better physical and chemical properties which can support crops. The recent work suggested that algae cultivation from livestock waste can be converted into bio-oil and other many valuable products. The waste fed or livestock integrated fish farming has good potential to generate the income.

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Introduction

During last decade, the livestock keeping practices were changed from mixed farming systems to specialized dairy farming with zero grazing under confinement. This system of livestock keeping is termed as confined animal feeding operations (CAFOs) which are specialized and intensive livestock farming. These trends of livestock keeping adapted to improve profitability have resulted in the pollution of air, water and soil (Gerber et al. 2005). Livestock waste is major source of green house gas, pollution, pathogens and odor. 40 % of global methane is produced by agriculture and livestock by-products followed by 18 % from waste disposal globally (EPA 1998). It is a rich source of energy and fertilizer elements which can be recovered for betterment of agriculture. Traditionally the dung cakes are utilized for cooking the food in rural areas particularly in developing countries. The increasing use of petroleum products forced us to utilize the ability of livestock waste for various possible energy products; among them biogas is most popular product in majority of countries of the world. Its production typically varies from 0.8 to 1.6 m^3 per adult unit per day. From 1 ton of manure with 20 % solid content, 20–25 cubic meter biogas can be produced with a total energy value of 100–125 kWh and the same can be utilized to generate 35–40 kWh of electricity and 55–75 kWh of heat energy (Burton and Turner 2003). Good quality organic fertilizer from animal waste provides an opportunity for the agricultural sector to reduce their reliance on chemical fertilizer which improves the soil fertility and sustainability. The use of animal waste as input for bio-energy conversion processes can allow farmers to take advantage of new markets for waste products. Proper utilization of cow dung and cow urine into manure, pesticides, medicines and other daily products can generate millions of employment opportunities in rural areas as well it can protect soil from chemicals and fertilizers and improve soil fertility (Vijay 2011). Bio-waste management has rapidly developed during the last decade in nearly all European countries. In the future about 40 % of the total waste in Europe can be handled by either composting or anaerobic digestion (Barth 2006).

Hence, there is a need for new waste management systems that make animal operations economically feasible and eco-friendly which ensures higher profit to livestock owners, recycling and sustainable use of nutrients with mitigation of environmental impacts.

Biogas production technology

Gas production from anaerobic biomass digestion is a famous technology. Billions of biogas units have been already established throughout the world. Biogas is a clean, efficient, and renewable source of energy, which can be used as a substitute for other nonrenewable fuels in order to save energy in rural areas particularly in developing countries of Asia and Africa. In European countries the biogas generation was 62 billion kWh in 2006 and among them Germany was the largest biogas producer with 4,300 plants generating 1,600 MW of electricity (Fachagentur für Nachwachsende Rohstoffe e.V. (FNR) 2009). India and China are the two leading Asian countries using biogas technology. The biogas produced is mainly used for household application in majority of developing countries of Asia and Africa.

The distribution of biogas through pipeline to end users is very costly. A novel system of biogas purification and bottling was recently developed at IIT, New Delhi (Vijay 2011). Pure biogas stored in cylinders is a marketable product and hence, can be easily used any time anywhere as LPG cylinders. The compressed natural gas (CNG) technology has become easily available and therefore, biomethane (or enriched biogas) which is similar to CNG can be used for all applications for which CNG is being used. The initial biogas bottling projects at villages of Maharashtra and Punjab states of India have successfully produced pure biogas with 98 % methane content which was compressed to 150 bar pressure for filling in cylinders.

The results of beginning studies of said biogas bottling plant in India and Pakistan are depicted in Table 1, which are quite encouraging and confirmed that biogas can be purified up to 98 % methane content and can be stored into CNG cylinders. Further, the stored biogas was used to run petrol-based auto rickshaws (Kapdi et al. 2006) and diesel engines (Ilyas 2006). The purified gas was used in mid-day meal scheme for cooking food for over 18,000 school students in India (Bamboriya 2012). The additional income of about \$111/day has been generated in 600 m^3 plant at Punjab, India from selling of slurry to farmers of adjoining areas as organic fertilizer. It was assumed that the said project is capable to recover the full cost of the project within 4–5 years. Therefore, results of initial studies of biogas bottling at India and Pakistan was found promising especially for developing countries and have a bright future especially to use in vehicular application especially in developing countries which are relying on import of petroleum. However, the initial huge capital requirement needs Government support through loans and subsidy. It is crude oil replacer; hence, to invest in such projects most of countries already have policies. The reliance on crude oil in developing countries can be substituted by use of bottled biogas at some extent. India has imported 159.26 and 163.59 MTs crude oil during 2009–10 and 2010–11, respectively, showing 2.72 % annual increase [Ministry of New and Renewable Energy (MNRE) 2010]. The economy of other countries was also affected greatly by importing crude oil (Ilyas 2006). Therefore, many countries are supporting these types of plants with loan and subsidy.

Biogas can be used to generate power through biogas-based power generator sets. About 0.75–0.8 m^3 biogas can generate 1 unit (1 kWA) of electricity and 10 kVA genset, if runs for 8 h can produces 80–90 units. The Biogas-based Power Generation Programme (BPGP) is the main policy in India to promote biogas power in which 73 projects were installed with a total capacity of 461 kW (Ministry of New and Renewable Energy (MNRE) 2010). The efforts of Government of India has started to give fruits as about 17538 MW power was generated from biomass which was shared 20 % from all sources of renewable energy (CSO 2012). Germany has 7,320 power generating biogas plant

Table 1 Potential of newer biogas purification and bottling technology

Country	Plant capacity (m^3)	Pure biogas produced (Kg/day)	No. of gas cylinders filled	Use of gas	Savings	Reference
Pakistan	60	21.6	4 cylinders of 3.5 kg	To run engines	Diesel of \$147/d	Ilyas (2006)
India	600	231	27 cylinders of 8 kg	Cooking	Replaced LPG of \$240/d	Kapdi et al. (2006)

with 2,997 MW capacity which was 13 % of all renewable power sources (Anon 2013). The other Asian countries such as Indonesia have potential to generate 684.83 Mw power from biogas (Widodo and Hendriadi 2005). China has started to introduce biogas-based power plants but until 2012 there was only 3 % plants used for power generation. They have tried the biogas power plants based on chicken manure and cattle manure with capacity of 18,000–60,000 kWh power daily (Chen et al. 2012). Many countries has already started producing power generation from biogas; however, literature reviewed in this regard suggested that this segment is still have a lot to do in coming days.

Composting

It is a well-known fact that fertilizers are necessary to be added in soil to increase the yield of crops. Particularly, the chemical fertilizer (NPK) has increased the crop production considerably. But long-time use of NPK is harmful for sustainability of crop production. Long-time use of chemical and organic fertilizers significantly affects the quality and productivity of soil mostly by improving availability of important elements to plants and soil-microbes (Acton and Gregorich 1995). Both can sustain or increase crop production and their use causes changes in soil chemical, physical and biological properties (Belay et al. 2002). In this regard one long-term experiment conducted at China (Li et al. 2012) is much informative. They have applied the possible combinations of NPK and composted pig manure (CPM) in soil used to grow corn (*Zea maize* L.) continuously for 21 years. They have analyzed the soil samples for important soil property parameters at onset of experiment and again after 21 years. The results are presented in Table 2 which shows that after 21 years, soil receiving chemical fertilizers alone had a significantly lower soil pH compared with the no fertilizer group (CK). The application of CPM alone and NPK + CPM increased the soil pH significantly. These results indicate that CPM application plays a critical role in maintaining the soil pH. Application of CPM could relieve the negative impact of N application on pH, and NPK + CPM application maintained the soil pH at the initial level. Thus, CPM application plays a critical role in maintaining the soil pH and is an essential practice to avoid acidification of Mollisol farmlands.

Table 2 Effect of long-time application of compost and chemical fertilizer on soil properties [Li et al. (2012)]

Soil properties	Initial	After 21 years			
		No fertilizer	Only NPK	Only CPM	NPK + CPM
pH (Soil:water, 1:2.5)	6.20	6.15^b	5.91^c	6.21^a	6.21^a
Total N (g kg^{-1})	3.0	2.1^c	2.7^{ab}	2.5^b	3.1^a
Total P (g kg^{-1})	0.7	0.6^b	0.9^a	0.7^b	1.0^a
Total K (g kg^{-1})	21.9	21.8^c	22.4^b	21.9^c	23.5^a
Available N (mg kg^{-1})	213	163^d	241^a	178^c	261^b
Available P (mg kg^{-1})	17.9	19.2^c	29.1^b	18.7^c	32.7^a
Available K (mg kg^{-1})	191	183	192	184	199

CPM Composted pig manure alone, *NPK* Nitrogen, Phosphorus and Potassium (K)

[a,b,c,d] Values followed by different letters in the same row are significantly different ($P < 0.05$)

Composting is a natural aerobic process that stabilizes a variety of organic matter and livestock manure. Well-composted manure has the odor of humus. Because of the heat produced during composting, well-controlled composting results in the destruction of both pathogens and weed seeds. The dead animals also can be effectively recycled via composting; however, feathers, teeth, and bone fragments may resist composting, which can be removed by mechanical screening if necessary. The poultry industry in the United States found a solution to its dead bird disposal problem by composting them by special procedure (Morrow and Ferket 1993). The success of the poultry industry in this area has stimulated a growing interest in the pig industry in the US to begin composting their mortalities (Kashmanian and Rynk 1995). The composting of pig carcasses may be carried out in bins built from treated wood, concrete or bales of hay, over a concrete floor (McCaskey et al. 1996). A layer of carcasses is placed over 1 feet layer of sawdust and then covered on all sides with 1 feet of sawdust. Add other layers until bin is full. Carcasses may be composted, whole or dismembered in case of large sows (Morrow et al. 1995). After 3 months, the compost may be turned manually or mechanically, and then allowed to stand another 3 months for the process to be completed (Fulhage 1993). If static-pile composting is being used, the compost is not turned for the whole period. Animal dead bodies can be buried into compost pile within 24 h of death and covered with thick layer of solid manure or soil. Composting is done in such a way that it will control odors, flies, rodents and other vermin (Morrow 2001). Dead animals with history of neurological disease, anthrax or other diseases and conditions kept under quarantine should not be composted (Belay et al. 2002). The pile composting is most common in India. Another method of composting used in India is NADEP method which is found to produce better nutrients than the conventional composting (Yadav 2012). Livestock wastes in Japan are mainly by subjecting to composting. About 50 and 25 % of solid waste from piggery and cattle, respectively, were subjected to composting. The liquid composting was also practiced in 2.1 and 6.9 % of cattle and pig waste, respectively, in Japan (Haga 1999). The composting systems used in Japan are mainly of five types, i.e., pile, box, rotary kiln, enclosed vertical type and open elongated type with turning device. For large ruminants the pile type and the open elongated type are mainly in use. The open elongated type and the enclosed vertical type are popular compost type for swine and poultry wastes. The pig manure is collected with much of water in developed countries, hence, difficult to be processed with composting. Separation of manure solids will improve its composting characteristics. Separated pig manure solids containing up to 79 % moisture have been composted successfully (Liao et al. 1993). It was suggested to use low-moisture bulking agents such as straw, sawdust, peat, peanut shells, rice hull, etc. for composting high-moisture manure (Georgacakis et al. 1996).

Vermicomposting

The earthworms eat the organic matter and excrete little pelleted material called "vermicompost". During vermicomposting, the important plant nutrients, such as N, P, K, and Ca, present in the organic waste are released and converted into forms that are more soluble and available to the plants. Vermicompost also contains biologically active substances such as plant growth regulators. Moreover, the worms themselves provide a protein source for animal feed. Table 3 shows the average nutrient contents (Nitrogen, Phosphorus and Potassium) of various types of vermicomposts reported by different authors, which show that vermicompost is a rich source of nitrogen phosphorus and potassium but there is high fluctuation in compositions reported by different workers.

The effectiveness of vermicompost on elephant foot yam crop at Navsari Agricultural University, Navsari, India, has been evaluated (Anonymous 2008). The results of 3-year trial revealed that the yield was observed higher with application of Vermicompost @ 5 t ha^{-1} than FYM or poultry manure (Table 4). Further, the use of vermicompost resulted in lower cultivation cost, higher net return and BCR (2.3) in the crop studied. In another trial about 70 % chemical fertilizer and 100 % FYM for mulberry cultivation can be substituted with vermicompost without affecting the quantity and quality of leaf produced (Sinha et al. 2005). The yield of potato, mustard, mulberry and marigold can be sustained even after replacement of 50 % of chemical fertilizer (NPK) with vermicompost (Gopakumar et al. 2000).

NAU, Navsari has studied vermicompost either made up of 100 % dung or replacement of 50 % dung by sugarcane trash, subabul or banana pseudo stem and found almost similar yield per bed, similar process time and economically profitable in all combinations with 50 % dung, but highest BCR was observed in 100 % dung treatment (Anonymous 2011). Other trial was conducted at Malaysia in which they have replaced the 75 % dung with palm oil mill industries waste with good result (Rupani et al. 2013). However, the mixture of other biomass with dung slows down the process. As 100 % cow dung took only 19 days to complete the cycle, it was prolonged up to 27, 40 and 70 days in case of dung replaced by 50, 70 and 100 %, respectively (Sinha et al. 2005). Hence, it can be said that vermicomposting is not only capable to replace chemical fertilizer but also may serve as business opportunity for rural poors.

Integrating composting and vermicomposting

The major problems associated with traditional thermophilic composting are the long duration of the process, the frequency of turning of the material, loss of nutrients during the prolonged composting process, and the heterogeneous nature of the product. The major drawback in the vermicomposting process is that it must be maintained at temperatures below 35 °C which does not remove all the pathogens. Thus, an integrated system approach that harvests advantages from both processes would be necessary to provide a product free of pathogens, and a product with desirable characteristics at a faster rate than either of the individual processes. If vermicomposting is used in combination with the traditional composting, the

Table 3 Average nutrient content of some common composts of animal and plant origin

Sr. no.	Manures/composts	C:N ratio	Nutrient content (%)			Reference
			N	P_2O_5	K_2O	
1	Farm yard manure	1: 25–40	0.80	0.41	0.74	Palaniappan (2010)
2	Poultry manure	1: 25–40	2.87	2.93	2.35	
3	Vermicompost	–	1.60	2.20	0.67	
4	Vermicompost	1:16.8	1.20	0.004	0.37	Jambhekar (1992)
5	Cattle waste Vermicompost	1: 8.32–19.20	0.51–1.61	0.19–1.02	0.15–0.73	Nagavallemma et al. (2004)
6	Palm oil waste-based Vermicompost	1: 13.23–32.72	1.29–2.53	–	7.79–11.97	Rupani et al. (2013)

Table 4 Effect of different composts treatments on tuber yield in elephant foot yam crop [Anonymous (2008)]

Treatments		Tuber yield (t ha^{-1})				Economics			
		2009–10	2010–11	2011–12	Pooled	Cost of cultivation (Rs ha^{-1})	Gross income (Rs ha^{-1})	Net income (Rs ha^{-1})	BCR
T_1	VC @ 5 t ha^{-1}	18.0	18.0	15.2	17.1	1,52,000	3,42,000	1,90,000	2.3
T_2	FYM @ 10 t ha^{-1}	15.7	16.0	15.6	15.8	1,56,900	3,16,000	1,59,100	2.0
T_3	PM @ 5 t ha^{-1}	14.6	15.7	14.0	14.8	1,58,000	3,96,000	1,38,000	1.9

VC Vermicompost, *PM* poultry manure, *FYM* farm yard manure

Table 5 Properties in the initial raw cattle manure and the substrates produced by the different treatments [Lazcano et al. (2008)]

Parameter	Raw cattle manure	Composting	Vermicomposting	Compos. + Vermi.
pH	7.70–8.94	8.86–8.07^{a}	7.73–7.51^{b}	7.85–7.14^{b}
C to N ratio	17 ± 0.74	17.5 ± 1.09^{a}	11.1 ± 0.24^{b}	11.3 ± 0.16^{b}
Total C (g Kg^{-1} dw)	399.2 ± 2.8	384.9 ± 2.7^{a}	314.0 ± 5.4^{b}	309.0 ± 8.6^{b}
NH_4^+N(mg Kg^{-1} dw)	610 ± 92	1235 ± 291^{b}	276 ± 24a	191 ± 30^{b}
NO_3^+N(mg Kg^{-1} dw)	19.5 ± 15	721 ± 184^{b}	917 ± 113^{b}	829 ± 110^{b}
Available P(g Kg^{-1} dw)	211 ± 6	342 ± 22^{a}	111 ± 3^{b}	109 ± 6^{b}

[a,b,c] Means with different superscripts within rows are significant differencing each other

required temperature for ensuring adequate pathogen kill would be achieved. Above said approach was tried at Spain using vermicomposting process for 30 and composting for 28 days in sequences (Ndegwa and Thompson 2001). Combining the two systems resulted in a superior product with more stability and homogeneity. Another trial of this combination of both processes has been successfully conducted at Spain (Lazcano et al. 2008) and India (Kaushik and Garg 2004). The chemical properties of the substrates processed by different treatments at experiment conducted at Spain (Lazcano et al. 2008) are summarized in Table 4. The quality parameters like pH and EC increased after composting and decreased after vermicomposting and the combined treatment (Table 5). The lowered C:N ratio is a good indicator of quality organic fertilizer and it was significantly lower in the treatments involving vermicomposting suggesting that it was more intensely decomposited. The concentration of mineral N (mainly NO_3^-) was significantly higher in all treatments than raw cattle manure, indicating an important degree of mineralization. Hence, earthworms change the degrading property of the manure. This was reflected by the lower EC, C to N ratio and pH in the substrates produced after vermicomposting.

Integration of waste treatment with algal cultivation

The carbon dioxide is a major component in the product gases from anaerobic digestion (Vijay 2011) and thermo-chemical conversion processes from livestock waste (Cantrell et al. 2008) which can be used for production of algal biomass. Algae can utilize carbon dioxide ten times more efficiently than terrestrial plants and can generate algal biomass and intracellular oil (Miao and Wu 2006). The algae cultivation has several benefits, i.e., rapid generation rates with biomass harvesting up to 50 metric tons $acre^{-1}$ $year^{-1}$ (Demirbas 2001); the accumulation of large amounts of fatty acids and hydrocarbons; as well as the ability to play a role in waste treatment. These algal products can be processed into many value-added products including bio-oil. So it is a most promising non-crop-based raw material for bio-fuel production. The algal biomass productivity of 6.83 g m^{-2} d^{-1} was observed in pond fed with biogas slurry contained 200 g m^{-3} of total nitrogen and 2.5 g m^{-3} of total dissolved phosphorus (Chen et al. 2012).

Profitable manure management by livestock fish integration

Slurry mixed water is very hazardous if not handled properly; however, simultaneously it is source of nutrients that can be recycled through integrating farming. Traditional practices of recycling effluent through agriculture, horticulture and aquaculture have been in use in several countries (Ghosh et al. 1999). Integration of fish with livestock farming is the best method for recycling of organic wastes. Cattle manure has been used extensively in India as a source of manure in carp polyculture (Sinha et al. 2005). Manure is

Table 6 Input and output of poultry waste-fed aquaculture (Tilapia and Common carp fish) [Little and Satapornvanit (1996)]

System	Inputs ($g\ m^{-2}\ d^{-1}$)	Outputs (g fish $m^{-2}\ d^{-1}$)	FCE (%)
Layer duck	6.71	2.82	42
Broiler chicken	10.0	2.87	27
Layer chicken	14.3	1.33	9

normally applied at 5,000–10,000 kg ha^{-1} $year^{-1}$, in low productive ponds but can be used as high as 25 tons ha^{-1} $year^{-1}$ (Lazcano et al. 2008). Livestock Research Station, Navsari (Gujarat) is utilizing the wallowing pond made for buffaloes for fresh water aquaculture with fish yield of 5 t ha^{-1} without any supplementary feeding (Anonymous 1998). The said pond was manured by dung and urine of buffaloes excreted during wallowing in summer months where as in winter months the slurry produced during washing of livestock sheds was directly drained into the said pond. This is very useful recommendation made available to farmers during 1998 from the said university (Anonymous 1998). The pond water is periodically pumped to irrigate the fodder farm with good result. The fish–pig integration is practiced in China, Taiwan, Vietnam, Thailand, Hong Kong, Malaysia, Hungary and some other European countries (Kumar and Sierp 2003). The N and P loadings of 4 kg ha^{-1} d^{-1} and 2 kg ha^{-1} d^{-1}, respectively, were defined as optimal for Tilapia monocultures in a series of experiment using both organic and inorganic fertilizers at the Asian Institute of Technology and other research stations. The yield up to 4–5 tonnes ha^{-1} of 200–250 g fish yield in around 6 months is possible if 1 fish m^{-2} is stocked. Higher stocking densities (up to 5 fish m^{-2}) can increase net fish yields further. If smaller fish are acceptable and multiple stocking and harvest are practiced, net extrapolated yields of 12 tonnes ha^{-1} $year^{-1}$ are possible (Knud Hansen 1998). The various poultry waste-fed aquaculture were tried at Japan with good fish yield (Little and Satapornvanit 1996). They got highest dry matter yield with highest feed conversion efficiency in egg laying duck-based aquaculture (Table 6).

Conclusion

Livestock waste can be recycled by many modern ways in order to combat rising energy prices, sustainable agricultural and reduce the environmental threats from traditional livestock waste management practices. India, China, Germany, Malaysia, Brazil are some of the leading countries in world to take advantage of biogas technology. The results of initial trials of biogas bottling plants in India demonstrated that the biogas can be pure up to 98 % methane content. The pure biogas can be successfully filled into CNG cylinders to use as vehicular fuel. The bottled biogas was found to replace crude oil, hence, having a bright future. The algae cultivation in waste water is good option to recycle the carbon dioxide a potent green house gas; moreover, algal biomass can be converted into many value-added products like bio-oil. The dead animals and birds can be successfully composted to make nutrient-rich compost. The composting of pig carcasses may be carried out in bins built from treated wood, concrete or bales of hay, over a concrete floor. High-moisture organic waste can be composted using low-moisture bulking agents such as straw, sawdust, peat, peanut shells, rice hull, etc. Vermicomposting is not only a powerful method of recycling the organic waste but it has potentiality for employment generation especially in rural areas. However, the better substrate in shorter period can be obtained from combined process of composting and vermicomposting. Integrated fish farming in wallowing pond or poultry or duck waste-fed aquaculture is a very promising enterprise that can provide additional income to farmers.

Conflict of interest We declare that we have no competing interests.

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