

REVIEW

Open Access



Current status of cow dung as a bioresource for sustainable development

Kartikey Kumar Gupta^{1*}, Kamal Rai Aneja² and Deepanshu Rana¹

Abstract

Cow dung, an excreta of bovine animal, is a cheap and easily available bioresource on our planet. Many traditional uses of cow dung such as burning as fuel, mosquito repellent and as cleansing agent are already known in India. Cow dung harbours a diverse group of microorganisms that may be beneficial to humans due to their ability to produce a range of metabolites. Along with the production of novel chemicals, many cow dung microorganisms have shown natural ability to increase soil fertility through phosphate solubilisation. Nowadays, there is an increasing research interest in developing the applications of cow dung microorganisms for biofuel production and management of environmental pollutants. This review focuses on recent findings being made on cow dung that could be harnessed for usage in different areas such as medicine, agriculture and industry.

Keywords: Cow dung, Biogas, Bioremediation, Enzymes, Antibiotics, Antimicrobial

Background

Cow dung can be defined as the undigested residue of consumed food material being excreted by herbivorous bovine animal species. Being a mixture of faeces and urine in the ratio of 3:1, it mainly consists of lignin, cellulose and hemicelluloses. It also contains 24 different minerals like nitrogen, potassium, along with trace amount of sulphur, iron, magnesium, copper, cobalt and manganese. The indigenous Indian cow also contain higher amount of calcium, phosphorus, zinc and copper than the cross-breed cow (Garg and Mudgal 2007; Randhawa and Kullar 2011). Cow dung harbours a rich microbial diversity, containing different species of bacteria (*Bacillus* spp., *Corynebacterium* spp. and *Lactobacillus* spp.), protozoa and yeast (*Saccharomyces* and *Candida*) (Nene 1999; Randhawa and Kullar 2011). Sawant et al. (2007) have isolated many different bacterial genera such as *Citrobacter koseri*, *Enterobacter aerogenes*, *Escherichia coli*, *Klebsiella oxytoca*, *Klebsiella pneumoniae*, *Kluyvera* spp., *Morgarella morganii*, *Pasteurella* spp., *Providencia*

alcaligenes, *Providencia stuartii* and *Pseudomonas* spp. from cow dung.

In India, 69.9 % population resides in rural areas (The Hindu 2011), where cow (*Bos indicus*) is major cattle and generates 9–15 kg dung/day (Werner et al. 1989; Brown 2003). Waste is generally meant for discarding because it may act as a source of pollution (Pongrácz and Pohjola 2004). However, if it is used in some other process such as feedstock it may be considered as co-product (Brown 2003). People in Indian villages use cow dung for cooking purpose by direct burning. It is also used in plastering of walls and floor in rural houses for providing insulation during winter and summer. Application of smoke generated from the burnt cow dung as mosquito repellent and subsequent ash as cleaning agent for kitchen utensils is an age old practice. Accordingly, different usage of cow dung by village peoples reflect the native knowledge associated with it. It also depict that cow plays an important role in village economy and has high socio-economic value (Dhama et al. 2005a).

Cow dung in India is also used as a co-product in agriculture, such as manure, biofertiliser, biopesticides, pestrepellent and as a source of energy (Dhama et al. 2005a). As per ayurveda, it can also act as a purifier for all the wastes in the nature (Randhawa and Khullar 2011). Therefore in India, Cow (*B. indicus*) is not only

*Correspondence: kartikey77@gmail.com

¹ Department of Botany and Microbiology, Gurukula Kangri University, Haridwar 249404, Uttarakhand, India
Full list of author information is available at the end of the article

just milk-producing animal but also truly considered as Gomata (mother of all) and Kamdhenu (Dhama et al. 2005a; Jarald et al. 2008). Detailed study of cow dung is gaining interest around the world and few attempts have been made for utilising its potential in the field of energy production, pharmaceutical products. The review intends to highlight the possible applications of cow dung particularly in the area ranging from energy, agriculture and environment to medicine for human welfare.

Source of energy

Dependence of mankind on non-renewable source of energy such as coal, oil and gases is increasing worldwide. In India, the main source of energy is coal, which accounts for 44 % of total energy consumption. Our country is now facing the shortage of coal supplies despite being the third largest coal producer in the world. According to energy information administration (EIA), our dependency on imported fossil fuels has risen to 38 % (USEIA 2014). Because of the limited availability of coal, an easily available, economical as well as environment friendly renewable source of energy is required. According to the United Nations Food and Agriculture Organisation (FAO), the animal waste on this planet produces around 55–65 % methane, which upon release in the atmosphere can affect global warming 21 times higher than the rate CO₂ does. Biogas, a mixture of different gases produced by anaerobic fermentation of organic matter from methanogenic bacteria, mainly constitutes methane (50–65 %) and CO₂ (25–45 %) (Sharma 2011). One kilogram of cow manure can produce 35–40 l of biogas when mixed with equal amount of water with hydraulic retention time (HRT) of 55–60 days maintained at an ambient temperature of 24–26 °C (Kalia and Singh 2004). Li et al. (2009) reported 67 ml/g methane yield from anaerobic digestion of cow manure, whose total and volatile solids were 23.4 and 13.8 g/l, respectively. Green bacteria such as *Pseudomonas* sp., *Azotobacter* sp. and other purple sulphur or purple non-sulphur bacteria are known to produce maximum amount of methane gas in comparison to other photosynthetic bacteria present in cow dung (Rana et al. 2014). The optimum production of biogas depends upon mesophilic (32–38 °C) and thermophilic (50–55 °C) temperature range (Kashyap et al. 2003). The inability of mesophilic microorganisms to survive in psychrophilic temperature range results in 70 % reduced production of biogas during winters in hilly areas (Kanwar and Guleri 1994). This may be due to the collapse of cell energy, outflow of intracellular substances or cell lysis of mesophiles at lower temperature (Gounot 1986). But many researchers reported a fair amount of biogas production under psychrophilic range of temperature using some modifications (Safley and Westerman 1990; Kanwar and Guleri 1994).

Cow dung is the major source of biogas or gobar gas production in India. The total population of female cows in India is 190.90 million out of which 151 million are indigenous whilst 39 million are crossbreed (Livestock Census 2012). Cow dung generated from 3–5 cattle/day can run a simple 8–10 m³ biogas plant which is able to produce 1.5–2 m³ biogas per day which is sufficient for the family 6–8 persons, can cook meal for 2 or 3 times or may light two lamps for 3 h or run a refrigerator for all day and can also operate a 3-KW motor generator for 1 h (Werner et al. 1989). A 1-m³ biogas plant has produced 28.78 l/kg (0.028 m³) and 32.76 l/kg (0.032 m³) of biogas respectively when daily feed with 22 kg of dung/m³ which is mixed with equal amount of water with 9–10 % of total solids. The maximum production of biogas from that plant is 39.00 l/kg (0.039 m³) and 40.04 l/kg (0.04 m³) respectively when operated at the temperature of 23.5 °C (Kalia and Singh 2004). On the other hand, farmer also gains 13.87 metric tons of organic fertiliser per year from the biogas plant. This co-production of biofertiliser also allow farmer to recover the initial investment for setting up of a biogas plant (Sharma 2011).

Though cow dung is solely used as the prime source for biogas production, but research continues to verify the potential of other sources for instance, addition of pig dung was found to have an enhanced effect. Mixture of cow and pig dung (60:40) showed 10 % increase in methane production as investigated by Li et al. (2014). Use of potato pulp and cow manure in the ratio of 20:80 also produced fair amount of methane in comparison to pure cow dung (Sanaei-Moghadam et al. 2014). Besides this, there are reports on comparative studies for biogas production where various feedstocks such as kitchen waste, corn waste and spent tea waste have been used along with cow dung in a ratio of 1:1 producing less average biogas after 25–30 days; however, cow dung alone produced approximately 50 % more biogas than these mixtures (Munda et al. 2012), thereby suggesting that other organic sources may produce biogas but cow dung still remains a potential source. In the light of above-discussed facts, biogas production can also be considered as an effective way of treating organic waste which may produce green house gases if remain untreated.

Supercapacitors are the in-between arrangement in electrochemical batteries which can store a large amount of energy that can be delivered with high power for few milliseconds (Gamby et al. 2001). They have high power density (10³–10⁴ W/kg), long cycle life (>10⁶ cycles), pulse power supply, low maintenance cost, simplicity and better safety compared to secondary batteries. The use of porous carbon as electrode material is widespread in supercapacitors. This porous carbon is synthesised by many different methods such as using silica or surfactant,

aerogels, organometallic compounds, chemical activation and physical activation. All these processes are costly and consume expensive precursors and time (Lee et al. 2006; Fang et al. 2009; Kim et al. 2012; Yang et al. 2012; Bhattacharjya et al. 2013; Inamdar et al. 2013; Bhattacharjya and Sung 2014; Yang et al. 2014). Now focus is shifting towards natural biomass as a potential source for carbon precursors. Several natural biomasses have been explored for production of activated carbon (Demiral and Demiral 2008; Hu et al. 2010; Li et al. 2010, 2011; Wei et al. 2011; Xu et al. 2012; Biswal et al. 2013; Falco et al. 2013; Huang et al. 2013; Wang et al. 2013; Bhattacharjya and Sung 2014). Activated carbon has recently been synthesised from cow dung by a modified chemical activation method, in which partially carbonised cow dung was treated with potassium hydroxide in the ratio of 2:1. The synthesised activated carbon when tested as supercapacitor electrodes in practical showed specific capacitance of 124 F/g at 0.1 A/g and retained up to 117 F/g at 1.0 A/g current density. It is also durable for long-term operations (Yang et al. 2012). The synthesis of activated carbon having high surface area along with optimum micropore and mesopore volume reflects excellent electrochemical application of cow dung for supercapacitors. The literature also suggest that biological waste like cow dung can be converted into a electrode material for other energy storage and conversion systems such as Li-ion batteries and fuel cells.

Agriculture management

Human population is increasing worldwide giving rise to intensive farming system and unsuitable cropland management that ultimately results in reduced soil fertility (Onwudike 2010; Bedada et al. 2014). Extensive use of chemical fertilisers is suggested for replenishment of nutritional deficiencies to increase crop yield. Many disadvantages of widespread use of chemical fertilisers include increase in soil acidity, mineral imbalance and soil degradation (Kang and Juo 1980; Ayoola and Makinde 2008) and even farmers nowadays do not prefer chemical fertilisers (Bedada et al. 2014). In composting, microorganisms decompose organic substrate aerobically into carbon dioxide, water, minerals and stabilised organic matter (Bernal et al. 2009; Kala et al. 2009; Vakili et al. 2015). Compost is added into the soil to improve nutrients and water-holding capacity (Arslan et al. 2008; Vakili et al. 2015). Recently, researchers observed that addition of cow dung to biomass generated from palm oil industries improves the physical and chemical properties including nutritional composition of compost. Palm oil biomass mixed with cow dung in the ratio of 1:3 significantly improved the compost quality with respect to various parameters such as pH, electrical conductivity and

C:N ratio (Vakili et al. 2015). Thus, cow dung may not only act as a substitute for chemical fertilisers because it supplements organic matter, but also as a conditioner for soil (Garg and Kaushik 2005; Yadav et al. 2013; Be'linger et al. 2014). Slurry from biogas plant is also a nutrient-rich source but it cannot be used at large scale because of its drawbacks such as eutrophication and leaching of the soil nutrients (Garg et al. 2005; Wachendorf et al. 2005; Islam et al. 2010; Lu et al. 2012; Guo et al. 2014).

Organic amendments alone may not offer sufficient nutrient supply to meet the demand (Palm et al. 1997; Gentile et al. 2011; Bedada et al. 2014). One way to counter this soil fertility problem is ISFM, i.e., Integrated Soil Fertility Management, a technique that makes use of both organic and inorganic resources resulting in greater yield response and better nutrient storage (Bedada et al. 2014; Ewusi-Mensah et al. 2015). For example, combination of cow dung with NPK (15:15:15) in the concentration of 3 t/ha and 100 kg/ha, respectively, showed marked increase of 8.9 t/ha in the yield of potato tuber in comparison to control that yielded only 1.8 t/ha. The organic carbon of the soil after treatment with this combination was found to be significantly increased from 1.33 to 3.21 %. The combination also improved soil organic matter, phosphate availability, exchangeable ions, effective cation exchange capacity and pH in comparison to untreated soil (Onwudike 2010). The same combination has also been reported to increase the yield of maize (Ayoola and Makinde 2008; Bedada et al. 2014).

Mineral soil phosphorus, a key nutrient limiting plant growth, is divided into three categories as per availability to plants, i.e., phosphorous soluble in the soil solution and available for plant uptake, labile phosphorous in the solid phase ready to be solubilised in soil solution and insoluble or fixed phosphorous in the solid phase (Kuhad et al. 2011; Swain et al. 2012). High amount of inorganic phosphates is added to soil but phosphorus ions are very reactive and most of the inorganic phosphorous is converted into insoluble phosphorous by immobilisation and chelation with metal ligands present in the soil, thereby becoming unavailable for plant uptake (Macias et al. 2003; Barroso et al. 2006; Kuhad et al. 2011; Swain et al. 2012). One of the methods for making insoluble phosphorous available to the plants is solubilisation through microorganisms (Arcand and Schneider 2006; Reyes et al. 2006; Swain et al. 2012). The recent areas where cow dung microorganisms are being used are in promoting soil fertility to improve crop yield. In this study by Swain et al. (2012), thermotolerant *Bacillus subtilis* strains have been recovered from cow dung with great potential in phosphate solubilisation. These *Bacillus* strains also possessed antagonistic activities against plant pathogens along with production of growth regulators. The findings

are significant as isolated bacterial strains being thermo-tolerant may possibly be used as bio-inoculant in agriculture of tropics where temperature during summer rises up to 42–45 °C (Swain et al. 2012).

Many biodynamic preparations obtained from cow dung have shown antagonistic effect against plant pathogens such as *Rhizoctonia bataticola* (Rupela et al. 2003; Somasundaram et al. 2007; Radha and Rao 2014). An investigation by Mary et al. (1986) revealed cow dung extract to be more effective than antibiotics like Penicillin, Paushamycin and Streptomycin in controlling bacterial blight of rice. *B. subtilis* strains are the most predominant isolates from culturable cow dung microflora. A few reports have shown the antagonistic properties of these *B. subtilis* strains against plant pathogens such as *Fusarium solani*, *Fusarium oxysporum* and *S. Sclerotiorum* (Basak and Lee 2002; Swain et al. 2006; Stalin et al. 2010; Swain et al. 2012). Plant pathogenic nematodes are one of the important pathogens of crops. Recently, a work by Lu et al. (2014) investigated 219 bacterial strains from cow dung for nematicidal activity against model nematode *Caenorhabditis elegans* and out of these, 17 strains killed more than 90 % of the tested nematode within 1 h. The strains identified included *Alcaligenes faecalis*, *Bacillus cereus*, *Proteus penneri*, *Providencia rettgeri*, *Pseudomonas aeruginosa*, *Pseudomonas otitidis*, *Staphylococcus sciuri*, *Staphylococcus xylosus*, *Microbacterium aerolatum* and *Pseudomonas beteli*. Out of these 14 strains also inhibited another nematode *Meloidogyne incognita*. This was for the first time that strains in the genera *Proteus*, *Providencia* and *Staphylococcus* from cow dung displayed nematicidal activity. Cow dung is conventionally applied in Indian subcontinental agriculture to enhance soil fertility. It not only improves the different properties of soil but also acts as a source of microorganisms producing biological nematicidal agents with no negative effect on environment. Therefore, use of cow dung should be promoted in the field of agriculture.

Bioremediation of environment pollutants

Toxic chemicals find their way into the human body, plant tissue and animals through absorption (Adams et al. 2014). Active pharmaceutical ingredients (API) serve as a blend of various drugs that are well known to pollute the aquatic environment (Kessler 2010). Agriculture run-off also contributes towards the pollution of water bodies through which water is supplied for human consumption. Presently, in India only 10 % of total waste water is treated and rest is discharged untreated (Singh and Kohli 2012). In industrial treatment plant in Patancheru, near Hyderabad (India), 0.9 mg ciprofloxacin per gram organic matter was found downstream from common contaminated river sediment (Kristiansson

et al. 2011; Larsson 2014). This condition is not only in India but also in China, U.S. and European countries as discharge of pharmaceuticals is also reported from these regions (Babic et al. 2007; Thomas et al. 2007; Fick et al. 2009; Kristiansson et al. 2011; Phillips et al. 2010; Larsson 2014). These practices are adversely affecting the environment quality which is directly related to the quality of life on earth. Discharge of these toxic compounds imparts negative effect on human health hence rejuvenation of environment is today's utmost need (Dhami et al. 2013; Adams et al. 2014).

Conventional methods such as dredging, incineration, use of sorbent materials, sinking and dispersion are not only economical but also environmentally unsustainable (Hilyard et al. 2008; Umanu et al. 2013; Adams et al. 2014). Biological methods are based upon application of appropriate microbes that can improve biodegradation in situ and ex situ (Cookson 1995; Freeman and Harris 1995; Umanu et al. 2013). Different methods which are used in removing of hydrocarbons are bioaugmentation, biostimulation, mycoremediation, phytoremediation, biosparging, bioventing and composting (Bahadure et al. 2013). Amongst these, bioremediation is the most common method in use for removal of hydrocarbons since 30 years (Ryan et al. 1991; Bahadure et al. 2013; Umanu et al. 2013). It involves the use of microorganisms with diverse metabolic capabilities to rapidly degrade hazardous organic pollutants to environmental safe level (Orji et al. 2012; Williams et al. 2013; Buvaneswari et al. 2013; Passatore et al. 2014).

Cow dung contains diverse group of microorganisms such as *Acinetobacter*, *Bacillus*, *Pseudomonas*, *Serratia* and *Alcaligenes* spp. which makes them suitable for microbial degradation of pollutants (Adebusoye et al. 2007; Akinde and Obire 2008; Umanu et al. 2013). Cow dung slurry maintained in the ratio of 1:10 or 1:25 is able to degrade the rural, urban and hospital wastes, including oil spillage to five basic elements (Randhawa and Kullar 2011). A study by Orji et al. (2012) highlights the importance of cow dung isolates, both bacterial and fungal, for reducing total petroleum hydrocarbons to 0 % in polluted mangrove soil. The bacterial isolates involved in the process belonged to genera *Pseudomonas*, *Bacillus*, *Citrobacter*, *Micrococcus*, *Vibrio*, *Flavobacterium* and *Corynebacterium*, whilst fungal isolates were the species from *Rhizopus*, *Aspergillus*, *Penicillium*, *Fusarium*, *Saccharomyces* and *Mucor*. The natural ability of cow dung microflora to degrade hydrocarbons in soil contaminated with engine oil is recently being investigated by Adams et al. (2014) where total petroleum hydrocarbon reduced up to 81 % by the metabolic activities of cow dung microorganisms such as *Bacillus*, *Staphylococcus*, *Pseudomonas*, *Flaviobacterium*, *Arthobacter*, *Enterobacter*,

Trichoderma, *Mucor* and *Aspergillus* spp. Umanu et al. (2013) suggested that the application of cow dung in an appropriate concentration may prove very efficient in biodegradation of water contaminated with motor oil. Some researchers also suggested the metabolic pathway for microbial degradation of polycyclic aromatic hydrocarbons. A *Mycobacterium* sp. isolated from contaminated soil of gaswork plant has shown the ability to degrade pyrene up to 60 % within 8 days maintained at 20 °C with several degrading products such as Cis-4,5-pyrene dihydrodiol, 4-5-phenanthrene dicarboxylic acid, 1-hydroxy-2-naphthoic acid, 2-carboxybenzaldehyde, phthalic acid and protocatechuic acid were recognised (Rehmann et al. 1998; Haritash and Kaushik 2009). Lignolytic fungi *Irpex lacteus* has also shown the ability to degrade phenanthrene to phenanthrene-9,10-dihydrodiol (Cajthaml et al. 2002; Haritash and Kaushik 2009). All these findings indicate that cow dung can supply nutrients and energy required for microbial growth thereby resulting in the bioremediation of pollutants.

Incineration is a method of choice for disposal of biomedical waste but it is not environmental friendly due to production of toxic gases giving rise to health complications. Another useful application of cow dung microorganisms is in the treatment of biomedical and pharmaceutical waste (Randhawa and Kullar 2011). *Cyathus stercoreus*, isolated from aged cow dung, is not only capable of degrading lignocelluloses in vitro (Wicklow et al. 1980; Freer and Detroy 1982; Wicklow 1992) but also an antibiotic enrofloxacin (Randhawa and Kullar 2011). Research by Pandey and Gundevia (2008) showed complete biodegradation of biomedical waste placed in culture medium of a cow dung fungus, *Periconiella*.

India is the second largest producer of pesticides in Asia with annual production of 90,000 tons out of which 2–3 % is utilised and the rest remain in soil causing environmental problems (WHO 1990; Randhawa and Kullar 2011). Few reports have been published describing the importance of cow dung microbiota in effective disposal of pesticides. Singh and Fulekar (2007) designed a bioreactor for bioremediation of phenol utilising cow dung as a source of biomass. This cow dung microbial consortium that included bacteria, fungi and actinomycetes was found effective in degrading phenol ranging from 100 to 1000 mg/l concentrations. Two bacteria namely *Pseudomonas plecoglossicida* and *Pseudomonas aeruginosa* present in microbial consortium have also been detected to completely degrade hazardous chemicals like cypermethrin and chlorpyrifos (Fulekar and Geetha 2008; Boricha and Fulekar 2009; Randhawa and Kullar 2011). Geetha and Fulekar (2008) utilised cow dung slurry in the ratio of 1:10 for bioremediation of pesticides namely chlorpyrifos, cypermethrin, fenvalerate and trichlopyr

butoxyethyl ester and found that all these pesticides are degraded into some intermediate or less harmful compounds.

Heavy metals enter into food chain through bioaccumulation from sources such as water, soil and air. These metals destroy the growth and metabolism of cells, disrupt the respiratory tract and accumulate in internal organs such as liver, heart and kidneys. Industrial waste is one of the major sources of heavy metal contamination of environment and involved in destruction of flora and fauna of water (Feng et al. 2004; Lakshmi et al. 2008; Kiaune and Singhasemanon 2011; Madu et al. 2011; Soni and Gupta 2011; Ali et al. 2013; Thajeel et al. 2013; Mohan and Gupta 2014). Remediation of heavy metals is commonly done by electrolytic deposition, electro dialysis, electrochemical, evaporation, precipitation, ion exchange, reduction, reverse osmosis, filtration, adsorption, chemical precipitation and distillation (Mohapatra et al. 2007, 2008; Mohan and Gupta 2014). All these methods are expensive and not environment friendly; hence, there is a need of cleaner and greener methods. Cow dung and its microorganisms have recently been tapped for the remediation of heavy metals like chromium, strontium and arsenic. Arsenic can be detoxified by methylation process. The ability of bacteria to methylate arsenic into volatile products mainly arsine, in the form of dimethylarsine, is already known (Bachofen et al. 1995). Mohapatra et al. (2008) have shown that cow dung can act as a major substrate for bacterial growth during removal of arsenic from arsenic-rich sludge by means of volatilisation. It was detected that methanogenic bacteria at substrate, i.e., cow dung concentration of 25 mg/l, could effectively volatilise around 35 % arsenic. Dry cow dung powder has recently been used as a source of adsorption for the removal of chromium from aqueous solution and achieved 73.8 % removal of chromium (Mohan and Gupta 2014). Another heavy metal, i.e., radiotoxic strontium which is very hazardous due to half-life of 29 years, imitates calcium in the body and increases the risk of bone cancer and leukaemia (Peterson et al. 2007; Barot and Bagla 2012). Barot and Bagla (2012) detected biosorption of a radiotoxic strontium (⁹⁰Sr) by dry cow dung powder. 350 mg of dry cow dung powder along with certain laboratory conditions such as pH 6, contact time of 10 min and agitation speed of 4000 rpm resulted in 85–90 % adsorption of strontium. Thus, dry cow dung powder may be preferred over other synthetic adsorbents because of their production cost, time and energy requirements. Cow dung is a cheap and economically viable resource which is easily available. According to the above-discussed data, cow dung can be employed with or without pre- or post-treatment as an excellent measure to bioremediate nonbiodegradable and

potentially toxic pollutants. Using cow dung for bioremediation is a simple and eco-friendly method as it does not produce any harmful by products. However, much more comprehensive studies are required to be done in this field.

Source of microbial enzymes

Microbial enzymes have got immense application because microbes can easily be cultivated and their enzyme can catalyse wide variety of hydrolytic and synthetic reactions (Illavarasi 2014). Many microbial enzymes have been isolated and studied for their industrial and commercial uses. However, still there is a continuous search for the potential microorganisms that are able to synthesise industrially feasible enzymes and microbial diversity of cow dung makes it a potential source for the said purpose (Dowd et al. 2008). *Bacillus* spp. from cow dung is capable of producing cellulose, carboxymethyl cellulose and cellulase (Das et al. 2010; Sadhu et al. 2013; Illavarasi 2014). In case of poor enzyme production, genetically improved strains can be constructed for enhanced enzyme production. For instance, Sadhu et al. (2014) described that cow dung *Bacillus* spp. can be mutated with NTG to increase the cellulase production from 9.4 to 16.3 U/mg proteins. Teo and Teoh (2011) detected several cow dung isolates producing enzymes like protease, lipase and esterase lipase. Xylanolytic bacteria are receiving increasing commercial interest in several industries such as enzyme-aided bleaching of paper (Encarna et al. 2004; Viikari et al. 1994), production of ethanol from plant biomass (Lamed et al. 1988), animal feed additives (Annison 1992) and in bread making (Maat et al. 1992). One member of xylanolytic bacteria *Paenibacillus favisporus* sp., from cow dung, was found to produce wide variety of hydrolytic enzymes such as xylanases, cellulases, amylases, gelatinase, urease and β -galactosidase (Encarna et al. 2004). Not only as a microbial source but cow dung may also serve as good substrate for enzyme production, for example, in production of detergent-stable dehairing protease by alkaliphilic *B. subtilis* (Vijayaraghavan et al. 2012), alkaline protease by *Halomonas* spp. (Vijayaraghavan and Vincent 2012) and fibrinolytic enzyme from *Pseudoalteromonas* sp. (Vijayaraghavan and Vincent 2014).

Human health management

Microbial products or their derivatives can kill or inhibit the growth of susceptible pathogenic microbes (Wiley et al. 2008). However, overuse and misuse of these antimicrobial agents have resulted in the development of resistance amongst pathogens (Aly et al. 2012; Sharif et al. 2013). At present, bacterial resistance against the antibiotics is of great concern for clinicians, public health

officials and researchers as it results in substantial morbidity, mortality and increased cost of treatment (Naiemi et al. 2006; Abo-state et al. 2012; Aly et al. 2012; Jayasanta et al. 2012; Ullah et al. 2012; Sharif et al. 2013). The pharmaceutical industries and healthcare systems of the world are continuously fighting multidrug-resistant strains of bacteria the last 50 years. Following this fundamental need to counter antibiotic resistance, one way is to search for new sources having possibilities for antibiotic-producing microorganisms. Soil is the prominent source from where hundreds of antibiotic-producing organisms have been isolated during the last five decades (Khamna et al. 2009; Hossain and Rahman 2014; Amin et al. 2015). Recently workers have started to explore other sources such as oceans (Wu et al. 2014). Bacteria colonising marine invertebrate (e.g., sponges and corals) are considered responsible for the production of antimicrobials (Zhang et al. 2012; Santos et al. 2015)

A relatively limited number of reports exist on the presence of antagonistic activity amongst cow dung microorganisms and antimicrobial activity of cow dung as a whole. Cow dung possesses antiseptic and prophylactic or disease preventive properties. It destroys the microorganism that causes disease and putrefaction. Medicinal properties of five products collectively known as panchgavya obtained from cow namely milk, ghee, curd, dung and urine are supported by their use in the preparation of various herbal medicines (Pathak and Kumar 2003; Jarald et al. 2008). Panchgavya therapy utilises these five products singly or in combination with herbal or mineral drugs for the treatment of many diseases like flu, allergies, colds, cough, asthma, renal disorders, gastrointestinal tract disorders, acidity, ulcer, wound healing, heart diseases, skin infections, tuberculosis, chickenpox, hepatitis, leprosy and several other bacterial and viral infections. Panchgavya also seems to be beneficial even for the diseases such as cancer, acquired immunodeficiency syndrome (AIDS) and diabetes. Immunostimulatory, immunomodulatory and antiinflammatory effects of panchgavya are also being mentioned in Ayurveda (Chauhan 2005; Dhama et al. 2005a; Donovan 2008; Jain et al. 2010; Sathasivam et al. 2010; Girija et al. 2013; Dhama et al. 2013). Recently, central nervous system action of panchgavya on spontaneous motor activity, muscle tone and pain has been determined in albino rats (Paliwal et al. 2013).

Cow dung has antifungal substance that inhibits the growth of coprophilous fungi (Dhama et al. 2005b; Joseph and Sankarganesh 2011; Dhama et al. 2013). *Eupenicillium bovisporum* present in cow dung produces patulodine-like compounds viz. CK2108A and CK2801B that possess significant antigungal activity (Dorothy and Frisvad 2002; Lehr et al. 2006). Lauková et al. (1998) detected

considerable numbers of enterococci in cow dung water with antilisterial effect. One isolated strain *Enterococcus faecalis* V24 was found to produce a heat stable, largely hydrophobic antimicrobial substance with significant antimicrobial activity against pathogenic Gram-negative bacteria. Possible applications of cow dung microorganisms in pharmaceutical industry has been indicated by Teo and Teoh (2011) and it was shown that isolate K4 possessed antibacterial activity against *E. coli*. Research has also been conducted on water, ethanol and n-Hexane extract of whole cow dung against *Candida*, *E. coli*, *Pseudomonas* and *Staphylococcus aureus* by Shrivastava et al. (2014) revealing their antimicrobial properties.

Mycobacterium vaccae, a non-pathogenic bacterium, first isolated from cow dung possesses antidepressant properties. When inhaled, it enhanced the growth of neuron which stimulates the production of serotonin and norepinephrine in the brain (Lowry et al. 2007). Its effects on anxiety and learning power were also tested on the mice and it showed good results when the mice fed with live *M. vaccae* (Matthews and Jenks 2013). Immunotherapy by killed *M. vaccae* vaccine has also been found effective in the treatment of asthma, cancer, leprosy and psoriasis (Rook and Stanford 1988; Lehrer et al. 1998). These reports suggest that cow dung may serve as a promising untapped source containing microorganisms, which hopefully may be connected to novel antimicrobial metabolites.

Conclusions

Cow dung host a wide variety of microorganisms varying in individual properties. Exploitation of cow dung microflora can contribute significantly in sustainable agriculture and energy requirements. It is one of the bioresources of this world which is available on large scale and still not fully utilised. The understanding of the mechanisms enabling cow dung microbes to degrade hydrocarbons can promote bioremediation of environmental pollutants. With recent advances in scientific research and techniques for complete genome sequences, the genes responsible for bioremediation can be identified. Another exciting area of research for future studies is developing microbial enzymes and antimicrobials. The production of enzymes by microorganisms from this cheap bioresource can find wide applications in various fields such as agriculture, chemistry and biotechnology. The application of cow dung microflora with considerable antimicrobial potential can result in the promotion of human health; however, comprehensive screening of these microorganisms for the production of antibacterial, antifungal and antiviral metabolites needed to be investigated. It is certainly evident that more detailed studies of cow dung are needed, as there is still a tremendous scope

for research and development to reach up to the industrial scale production of antibiotics and enzymes. In this way, cow dung may be considered as an easily available bioresource that holds a great potential for sustainable development in the near future.

Abbreviations

USEIA: United States energy information administration; ISFM: integrated soil fertility management; NPK: nitrogen, phosphorus, potassium; NTG: *N*-methyl-*N'*-nitro-*N*-nitrosoguanidine.

Authors' contributions

KKG and DR contributed to the preparation of the manuscript. KRA contributed to the general advice and improving of the manuscript. All authors read and approved the final manuscript.

Author details

¹ Department of Botany and Microbiology, Gurukula Kangri University, Haridwar 249404, Uttarakhand, India. ² Department of Microbiology, Kurukshetra University, Kurukshetra 136119, Haryana, India.

Competing interests

The authors declare that they have no competing interests.

Received: 22 October 2015 Accepted: 23 May 2016

Published online: 01 June 2016

References

- Abo-State MA, Mahdy HM, Ezzat SM, Abd El Shakour EH, El-Bahnasawy MA (2012) Antimicrobial resistance profiles of *Enterobacteriaceae* isolated from Rosetta Branch of River Nile, Egypt. *World Appl Sci J* 19:1234–1243
- Adams GO, Tawari-Fufeyin P, Ehinomen I (2014) Laboratory scale bioremediation of soils from automobile mechanic workshops using cow dung. *J Appl Environ Microbiol* 2:128–134
- Adebusoye SA, Ilori MO, Amund OO, Teniola OD, Olatope SO (2007) Microbial degradation of petroleum hydrocarbons in a polluted tropical stream. *World J Microbiol Biotechnol* 23:1149–1159
- Akande SB, Obire O (2008) Aerobic heterotrophic bacteria and petroleum-utilizing bacteria from cow dung and poultry manure. *World J Microbiol Biotechnol* 24:1999–2002
- Ali H, Khan E, Sajad M (2013) Phytoremediation of heavy metals-concepts and applications. *Chemosphere* 91:869–881
- Aly MEA, Essam TM, Amin MA (2012) Antibiotic resistance profile of *Escherichia coli* strains isolated from clinical specimens and food samples in Egypt. *Int J Microbiol Res* 3:176–182
- Amin M, Rakhisi Z, Ahmady AZ (2015) Isolation and identification of *Bacillus* Species from soil and evaluation of their antibacterial properties. *Avicenna J Clin Microb Infec* 2:e23233
- Annisson G (1992) Commercial enzyme supplementation of wheat based diets raises ileal glycanase activities and improves apparent metabolisable energy, starch and pentosan digestibilities in broiler chickens. *Anim Feed Sci Technol* 38:105–121
- Arcand MM, Schneider KD (2006) Plant and microbial-based mechanisms to improve the agronomic effectiveness of phosphate rock: a review. *Anais da Academia Brasileira de Ciências* 78:791–807
- Arslan EI, Öbek E, Kirba S, Pek U, Topal M (2008) Determination of the effect of compost on soil microorganisms. *Int J Sci Technol* 3:151–159
- Ayoola OT, Makinde EA (2008) Performance of green maize and soil nutrient changes with fortified cow dung. *Afr J Plant Sci* 2:19–22
- Babic S, Mutavdzic D, Asperger D, Horvat AJM, Kaštelan-Macan M (2007) Determination of veterinary pharmaceuticals in production wastewater by HPTLC-video densitometry. *Chromatographia* 65:105–110
- Bachofen R, Birch L, Buchs U, Ferloni P, Flynn I, Jud G, Tahedel H, Chasteen TG (1995) Volatilization of arsenic compounds by microorganisms. In: Hinchee RE (ed) *Bioremediation of inorganics*. Battelle Press, Columbus

- Bahadure S, Kalia R, Chavan R (2013) Comparative study of bioremediation of hydrocarbon fuels. *Int J Biotechnol Bioeng Res* 4:677–686
- Barot NS, Bagla HK (2012) Biosorption of radiotoxic ^{90}Sr by green adsorbent: dry cow dung powder. *J Radioanal Nucl Chem* 294:81–86
- Barroso CB, Pereira GT, Nahas E (2006) Solubilization of CaHPO_4 and AlPO_4 by *Aspergillus niger* in culture media with different carbon and nitrogen sources. *Braz J Microbiol* 37:434–438
- Basak AB, Lee MW (2002) In vitro inhibitory activity of cow urine and cow dung of *Fusarium Solani* F Sp. Cucurbitae. *Microbiology* 30:51–54
- Bélanger G, Rochette P, Chantigny M, Ziadi N, Angers D, Charbonneau E, Pellerin D, Liang C (2014) Nitrogen availability from dairy cow dung and urine applied to forage grasses in eastern Canada. *Can J Plant Sci* 95:55–65
- Bedada W, Karlton E, Lemenih M, Tolera M (2014) Long-term addition of compost and NP fertilizer increases crop yield and improves soil quality in experiments on smallholder farms. *Agric Ecosyst Environ* 195:193–201
- Bernal MP, Alburquerque JA, Moral R (2009) Composting of animal manures and chemical criteria for compost maturity assessment—review. *Bioresour Technol* 100:5444–5453
- Bhattacharjya D, Sung YJ (2014) Activated carbon made from cow dung as electrode material for electrochemical double layer capacitor. *J Power Sources* 262:224–231
- Bhattacharjya D, Park HY, Kim MS, Choi HS, Inamdar SN, Yu JS (2013) Nitrogen-doped carbon nanoparticles by flame synthesis as anode material for rechargeable lithium-ion batteries. *Langmuir* 30:318–324
- Biswal M, Banerjee A, Deo M, Ogale S (2013) From dead leaves to high energy density supercapacitors. *Energy Environ Sci* 6:1249–1259
- Boricha H, Fulekar MH (2009) *Pseudomonas plecoglossicida* as a novel organism for the bioremediation of cypermethrin. *Biol Med* 1:1–10
- Brown RC (ed) (2003) *Biorenewable resources—engineering new products from agriculture*. Iowa state press, London
- Buvanewari S, Damodarkumar S, Murugesan S (2013) Bioremediation studies on sugar-mill effluent by selected fungal species. *Int J Curr Microbiol App Sci* 2:50–58
- Cajthaml T, Möder M, Kačer P, Šašek V, Popp P (2002) Study of fungal degradation products of polycyclic aromatic hydrocarbons using gas chromatography with ion trap mass spectrometry detection. *J Chromatogr A* 974:213–222
- Chauhan RS (2005) Cowpathy: a new version of ancient science. *Employ News* 30:1–2
- Cookson JT (ed) (1995) *Bioremediation engineering: design and application*. McGraw-Hill, New York
- Das A, Bhattacharya S, Murali L (2010) Production of cellulose from thermophilic *Bacillus* sp. isolated from cow dung. *Am Eurasian J Agric Environ Sci* 8:685–691
- Demiral H, Demiral I (2008) Surface properties of activated carbon prepared from wastes. *Surf Interface Anal* 40:612–615
- Dhama K, Chauhan RS, Singhal L (2005a) Anti-cancer activity of cow urine: current status and future directions. *Int J Cow Sci* 1:1–25
- Dhama K, Rathore R, Chauhan RS, Tomar S (2005b) Panchgavya: an overview. *Int J Cow Sci* 1:1–15
- Dhama K, Chakraborty S, Tiwari R (2013) Panchgavya therapy (Cowpathy) in safeguarding health of animals and humans—a review. *Res Opin Anim Vet Sci* 3:170–178
- Dhami JK, Singh H, Gupta M (2013) Industrialization at the cost of environment degradation—a case of leather and iron and steel industry from Punjab economy. *Innov J Bus Manag* 2:19–21
- Donovan B (2008) Breathe in the cow dung, cockies—it'll cut your cancer risk. *In: The New Zealand Herald*. http://www.nzherald.co.nz/nz/news/article.cfm?c_id=1&objectid=10489178. Accessed 25 Jul 2015
- Dorothy ET, Frisvad JC (2002) *Eupenicillium bovismosum*, a new species from dried cow manure in Wyoming. *Mycologia* 94:240–246
- Dowd SE, Callaway TR, Wolcott RD, Sun Y, McKeenan T, Hagevoort RG, Edrington T (2008) Evaluation of the bacterial diversity in the feces of cattle using 16S rDNA bacterial tag-encoded FLX amplicon pyrosequencing (bTEFAP). *BMC Microbiol* 8:125
- Encarna VZ, Trinidad DM, Margarita P, Rau R, Ramo'n RM, Toma GV (2004) *Paenibacillus favisporus* sp. nov., a xylanolytic bacterium isolated from cow faeces. *Int J Syst Evol Microbiol* 54:59–64
- Ewusi-Mensah N, Logah V, Akraji EJ (2015) Impact of different systems of manure management on the quality of cow dung. *Commun Soil Sci Plant Anal* 46:137–147
- Falco C, Sieben JM, Brun N, Sevilla M, Mauelen T, Morallón E, Cazorla-Amorós D, Titirici MM (2013) Hydrothermal carbons from hemicellulose-derived aqueous hydrolysis products as electrode materials for supercapacitors. *Chem Sus Chem* 6:374–382
- Fang B, Kim JH, Kim M, Yu JS (2009) Ordered hierarchical nanostructured carbon as a highly efficient cathode catalyst support in proton exchange membrane fuel cell. *Chem Mater* 21:789–796
- Feng Q, Lin Q, Gong F, Sugita S, Shoya M (2004) Adsorption of lead and mercury by rice husk ash. *J Colloid Interf Sci* 278:1–8
- Fick J, Söderström H, Lindberg RH, Chau DNP, Tysklind M, Larsson DGJ (2009) Contamination of surface, ground, and drinking water from pharmaceutical production. *Environ Toxicol Chem* 28:2522–2527
- Freeman HM, Harris EF (1995) Hazardous waste remediation: innovation treatment technologies. Technomic Publ Co., Inc., Lancaster, p 342
- Freer SN, Detroy RW (1982) Biological delignification of C-labelled lignocelluloses by basidiomycetes: degradation and solubilization of the lignin and cellulose components. *Mycologia* 74:943–951
- Fulekar MH, Geetha M (2008) Bioremediation of Chlorpyrifos by *Pseudomonas aeruginosa* using scale up technique. *J Appl Biosci* 12:657–660
- Gamby J, Taberna PL, Simon P, Fauvarque JF, Chesneau M (2001) Studies and characterisations of various activated carbons used for carbon/carbon supercapacitors. *J Power Sources* 101:109–116
- Garg VK, Kaushik P (2005) Vermistabilization of textile mill sludge spiked with poultry droppings by an epigeic earthworm *Eisenia foetida*. *Bioresour Technol* 96:1063–1071
- Garg AK, Mudgal V (2007) Organic and mineral composition of Gomeya (cow dung) from Desi and crossbred cows—a comparative study. *Int J Cow Sci* 3:1–2
- Garg RN, Pathak H, Das DK, Tomar RK (2005) Use of fly ash and biogas slurry for improving wheat yield and physical properties of soil. *Environ Monit Assess* 107:1–9
- Geetha M, Fulekar MH (2008) Bioremediation of pesticides in surface soil treatment unit using microbial consortia. *Afr J Environ Sci Technol* 2:36–45
- Gentile R, Vanlauwe B, Chivenge P, Six J (2011) Trade-offs between the short- and long-term effects of residue quality on soil C and N dynamics. *Plant Soil* 338:159–169
- Girija D, Deepa K, Xavier F, Antony I, Shidhi PR (2013) Analysis of cow dung microbiota—a metagenomic approach. *Indian J Biotech* 12:372–378
- Gounot AM (1986) Psychrophilic and psychrotrophic microorganisms. *Experimentia* 42:1192–1197
- Guo Y, Tang H, Li G, Xie D (2014) Effects of cow dung biochar amendment on adsorption and leaching of nutrient from an acid yellow soil irrigated with biogas slurry. *Water Air Soil Pollut* 225:1820
- Haritash AK, Kaushik CP (2009) Biodegradation aspects of polycyclic aromatic hydrocarbons (PAHs): a review. *J Hazard Mater* 169:1–15
- Hilyard EJ, Jones-Meehan JM, Spargo BJ, Hill RT (2008) Enrichment, isolation, and phylogenetic identification of polycyclic aromatic hydrocarbon-degrading bacteria from Elizabeth river sediments. *Appl Environ Microbiol* 74:1176–1182
- Hossain MN, Rahman MM (2014) Antagonistic activity of antibiotic producing *Streptomyces* sp. against fish and human pathogenic bacteria. *Braz Arch Biol Technol* 57:233–237
- Hu B, Wang K, Wu L, Yu SH, Antonietti M, Titirici MM (2010) Engineering carbon materials from the hydrothermal carbonization process of biomass. *Adv Mater* 22:813–828
- Huang C, Sun T, Hulicova-Jurcakova D (2013) Wide electrochemical window of supercapacitors from coffee bean derived phosphorus rich carbons. *Chem Sus Chem* 6:2330–2339
- Illavarasi S (2014) Isolation and identification of cellulase producing bacteria from cow dung. *SIRJ-MBT* 1
- Inamdar S, Choi HS, Wang P, Song MY, Yu JS (2013) Sulfur-containing carbon by flame synthesis as efficient metal-free electrocatalyst for oxygen reduction reaction. *Electrochem Commun* 30:9–12
- Islam MR, Rahman SME, Rahman MM, Oh DH, Ra CS (2010) The effects of biogas slurry on the production and quality of maize fodder. *Turk J Agric For* 34:91–99

- Jain NK, Gupta VB, Garg R, Silawat N (2010) Efficacy of cow urine therapy on various cancer patients in Mandsaur District, India—a survey. *Int J Green Pharm* 4:29–35
- Jarald E, Edwin S, Tiwari V, Garg R, Toppo E (2008) Antioxidant and antimicrobial activities of cow urine. *Global J Pharmacol* 2:20–22
- Jeyasanta KI, Aiyamperumal V, Patterson J (2012) Prevalence of antibiotic resistant *Escherichia coli* in sea foods of Tuticorin coast, southeastern India. *Adv Biol Res* 6:70–77
- Joseph B, Sankarganesh P (2011) Antifungal efficacy of panchgavya. *Int J Pharm Tech Res* 3:585–588
- Kala DR, Rosenani AB, Fauziah CI, Thohirah LA (2009) Composting oil palm wastes and sewage sludge for use in potting media of ornamental plants. *Malays J Soil Sci* 13:77–91
- Kalia A, Singh S (2004) Development of a biogas plant. *Energy Sources* 26:707–714
- Kang BT, Juo ASR (1980) Management of low-activity clay soils in Tropical Africa for food crop production. In: Terry ER, Oduro KA, Caveness F (eds) *Tropical root crops: research strategies for the 1980s*. IDRC, Ottawa, p 129–133
- Kanwar SS, Guleri RL (1994) Performance evaluation of a family size rubber balloon biogas plant under hilly conditions. *Biores Technol* 50:119–121
- Kashyap DR, Dadhich KS, Sharma SK (2003) Biomethanation under psychrophilic conditions: a review. *Bioresour Technol* 87:147–153
- Kessler R (2010) Pharmaceutical factories as a source of drugs in water. *Environ Health Perspect* 118:383
- Khamna S, Yokota A, Lumyong S (2009) Actinomycetes isolated from medicinal plant rhizosphere soils: diversity and screening of antifungal compounds, indole-3-acetic acid and siderophore production. *World J Microbiol Biotechnol* 25:649–655
- Kiaune L, Singhasemanon N (2011) Pesticidal copper(I)oxide: environmental fate and aquatic toxicity. *Rev Environ Contam T* 213:1–26
- Kim JH, Fang B, Song MY, Yu JS (2012) Topological transformation of thioether-bridged organosilicas into nanostructured functional materials. *Chem Mater* 24:2256–2264
- Kristiansson E, Fick J, Janzon A, Grabic R, Rutgersson C, Weijdegård B, Söderström H, Larsson DJ (2011) Pyrosequencing of antibiotic-contaminated river sediments reveals high levels of resistance and gene transfer elements. *PLoS One* 6:e17038
- Kuhad RC, Singh S, Lata Singh A (2011) Phosphate solubilising microorganisms. In: Singh A, Parmar N, Kuhad RC (eds) *Bioaugmentation, biostimulation and biocontrol, soil biology series*, vol 28. Springer, Heidelberg, pp 65–84
- Lakshmi SS, Gayathri M, Sudha PN (2008) Study on removal of chromium (VI) from aqueous solution using sulphonated black rice husk ash and sulphonated white rice husk ash. *Nat Environ Pollut Technol* 7:733–736
- Lamed R, Bayer E, Saha BC, Zeikus JG (1988) Biotechnological potential of enzyme from unique thermophiles. In: Durand G, Bobichon L, Florent J (eds) *Proceedings of the 8th international biotechnology symposium*, Paris, 1988
- Larsson DJ (2014) Antibiotics in the environment. *Upsala J Med Sci* 119:108–112
- Lauková A, Czikková S, Vasilková Z, Juris P, Mareková M (1998) Occurrence of bacteriocin production among environmental *Enterococci*. *Lett Appl Microbiol* 27:178–182
- Lee J, Kim J, Hyeon T (2006) Recent progress in the synthesis of porous carbon materials. *Adv Mater* 18:2073–2094
- Lehr NA, Meffert A, Antelo L, Sterner O, Anke H, Weber RWS (2006) Antiamoebins, myrocin B and the basis of antifungal biosis in the coprophilous fungus *Stilbella erythrocephala* (syn. *Stilbella fimetaria*). *FEMS Microbiol Ecol* 55:105–112
- Lehrer A, Bressanelli A, Wachsmann V, Bottasso O, Bay ML, Singh M, Stanford C, Stanford J (1998) Immunotherapy with *Mycobacterium vaccae* in the treatment of psoriasis. *FEMS Immunol Med Microbiol* 21:71–77
- Li R, Chen S, Li X (2009) Anaerobic co-digestion of kitchen waste and cattle manure for methane production. *Energy Source Part A Recovery Util Environ Eff* 31:1848–1856
- Li X, Han C, Chen X, Shi C (2010) Preparation and performance of straw based activated carbon for supercapacitor in non-aqueous electrolytes. *Microporous Mesoporous Mater* 131:303–309
- Li X, Xing W, Zhuo S, Zhou J, Li F, Qiao SZ, Lu GQ (2011) Preparation of capacitor's electrode from sunflower seed shell. *Bioresour Technol* 102:1118–1123
- Li J, Jha AK, Bajracharya TR (2014) Dry anaerobic co-digestion of cow dung with pig manure for methane production. *Appl Biochem Biotechnol* 173:1537–1552
- Ministry of Agriculture Department of Animal Husbandry Dairying and Fisheries Krishi Bhawan (2012) *Livestock Census—2012 All India Report*. Ministry of Agriculture Department of Animal Husbandry Dairying and Fisheries Krishi Bhawan, New Delhi
- Lowry CA, Hollis JH, De Vries A, Pan B, Brunet LR, Hunt JRF, Lightman SL (2007) Identification of an immune-responsive mesolimbocortical serotonergic system: potential role in regulation of emotional behavior. *Neuroscience* 146:756–772
- Lu J, Jiang L, Chen D, Toyota K, Strong PJ, Wang H, Hirasawa T (2012) Decontamination of anaerobically digested slurry in a paddy field ecosystem in Jiaying region of China. *Agric Ecosyst Environ* 146:13–22
- Lu H, Wang X, Zhang K, Xu Y, Zhou L, Li G (2014) Identification and nematicidal activity of bacteria isolated from cow dung. *Ann Microbiol* 64:407–411
- Maat J, Roza M, Verbakel J, Stam H, Santos de Silva MJ, Bosse M, Hessing JGM, Egmond MR, Hagemans MLD, Gorcom RFM (1992) Xylanases and their application in bakery. In: Visser J, van Someren MAK, Beldman G, Voragen AGJ (eds) *Xylans and xylanases*. Elsevier, Amsterdam, pp 349–360
- Macías FA, Marin D, Oliveros-Bastidas A, Varela RM, Simonet AM, Carrera C, Molinillo JMG (2003) Allelopathy as a new strategy for sustainable ecosystems development. *Biol Sci Space* 17:18–23
- Madu PC, Akpaiyo GD, Ikoku P (2011) Biosorption of Cr²⁺, Pb²⁺, and Cd²⁺ ions from aqueous solution using modified and unmodified millet chaff. *J Chem Pharm Res* 3:467–477
- Mary CA, Dav VPS, Karunakaran K, Nair NR (1986) Cow dung extract for controlling bacterial blight. *Int Rice Res News* 11:19
- Matthews DM, Jenks SM (2013) Ingestion of *Mycobacterium vaccae* decreases anxiety-related behavior and improves learning in mice. *Behav Process* 96:27–35
- Mohan L, Gupta D (2014) Study on removal of chromium from aqueous solution using dry cow dung powder. *J Chem Pharm Res* 6:1066–1070
- Mohapatra D, Mishra D, Rout M, Chaudhury GR (2007) Adsorption kinetics of natural dissolved organic matter and its impact on arsenic(V) leachability from arsenic loaded ferrihydrite and Al-ferrihydrite. *J Environ Sci Health Part A* 42:81–88
- Mohapatra D, Mishra D, Chaudhury RG, Das RP (2008) Removal of arsenic from arsenic rich sludge by volatilization using anaerobic microorganisms treated with cow dung, soil and sediment contamination. *An Int J* 17:301–311
- Munda US, Pholane L, Kar DD, Meikap BC (2012) Production of bioenergy from composite waste materials made of corn waste, spent tea waste, and kitchen waste co-mixed with cow dung. *Int J Green Energy* 9:361–375
- Naiemi NA, Heddema ER, Bart A, De Jonge E, Vandembroucke-Grauls CM, Savelkoul PH, Duim B (2006) Emergence of multidrug-resistant Gram-negative bacteria during selective decontamination of the digestive tract on an intensive care unit. *J Antimicrob Chemother* 58:853–856
- Nene YL (1999) Utilizing traditional knowledge in agriculture. *Traditional knowledge system of India and Sri Lanka*, pp 32–38
- Onwudike SU (2010) Effectiveness of cow dung and mineral fertilizer on soil properties, nutrient uptake and yield of sweet potato (*Ipomoea batatas*) in Southeastern Nigeria. *Asian J Agric Res* 4:148–154
- Orji FA, Ibiere AA, Dike EN (2012) Laboratory scale bioremediation of petroleum hydrocarbon polluted mangrove swamp in the Niger Delta using cow dung. *Malays J Microbiol* 8:219–228
- Paliwal R, Sahni YP, Singh SK, Sen S (2013) Effect of panchgavya on central actions in albino rats. *Pharma Sci Monit* 4:3940–3946
- Palm CA, Robert JKM, Stephen MN (1997) Combined use of organic and inorganic nutrient sources for soil fertility maintenance and replenishment. In: Hatfield J, Bigham JM, Krai DM, Viney MK (eds) *Replenishing soil fertility in Africa*. SSSA, Madison
- Pandey A, Gundevia HS (2008) Role of the fungus—*Periconiella* sp. in destruction of biomedical waste. *J Environ Sci Eng* 50:239–240
- Passatore L, Rossetti S, Juwarkar AA, Massacci A (2014) Phytoremediation and bioremediation of polychlorinated biphenyls (PCBs): state of knowledge and research perspectives. *J Hazard Mater* 278:189–202

- Pathak ML, Kumar A (2003) Cow prasing and importance of Panchyagavya as medicine. *Sachitra Ayurveda* 5:56–59
- Peterson J, MacDonell M, Haroun L, Monette F, Hildebrand RD, Taboas A (2007) Radiological and chemical fact sheets to support health risk analyses for contaminated areas. Argonne Natl Lab Environ Sci Division 133
- Phillips PJ, Smith SG, Kolpin DW, Zaugg SD, Buxton HT, Furlong ET, Esposito K, Stinson B (2010) Pharmaceutical formulation facilities as sources of opioids and other pharmaceuticals to wastewater treatment plant effluents. *Environ Sci Technol* 44:4910–4916
- Pongrácz E, Pohjola VJ (2004) Re-defining waste, the concept of ownership and the role of waste management. *Resour Conserv Recycl* 40:141–153
- Radha TK, Rao DLN (2014) Plant growth promoting bacteria from cow dung based biodynamic preparations. *Indian J Microbiol* 54:413–418
- Rana G, Mandal T, Mandal NK (2014) Generation of high calorific fuel gas by photosynthetic bacteria isolated from cow dung. *Int J Res* 1:115–128
- Randhawa GK, Kullar JS (2011) Bioremediation of pharmaceuticals, pesticides, and petrochemicals with gomeya/cow dung. *ISRN Pharmacol*. doi:10.5402/2011/362459
- Rehmann K, Noll HP, Steinberg CE, Kettrup AA (1998) Pyrene degradation by *Mycobacterium* sp. strain KR2. *Chemosphere* 36:2977–2992
- Reyes I, Valery A, Valdúz Z (2006) Phosphate-solubilizing microorganisms isolated from rhizospheric and bulk soils of colonizer plants at an abandoned rock phosphate mine. *Plant Soil* 287:69–75
- Rook GAW, Stanford JL (1988) Immunotherapeutic composition of killed cells from *mycobacterium vaccae*. US patent 4724144. 11 Nov 1988
- Rupela OP, Gopalakrishnan S, Krajewski M, Sriveni M (2003) A novel method for the identification and enumeration of microorganisms with potential for suppressing fungal plant pathogens. *Biol Fertil Soils* 39:131–134
- Ryan JR, Loehr RC, Rucker E (1991) Bioremediation of organic contaminated soils. *J Hazard Mater* 28:159–169
- Sadhu S, Saha P, Sen SK, Mayilraj S, Maiti TK (2013) Production, purification and characterization of a novel thermotolerant endoglucanase (CMCase) from *Bacillus* strain isolated from cow dung. *Springerplus* 2:1–10
- Sadhu S, Ghosh PK, Aditya G, Maiti TK (2014) Optimization and strain improvement by mutation for enhanced cellulase production by *Bacillus* sp. (MTCC10046) isolated from cow dung. *J King Saud Univ Sci* 26:323–332
- Safley LM, Westerman PW (1990) Psychrophilic anaerobic digestion of animal manure: proposed design methodology. *Biol Wastes* 34:133–148
- Sanaei-Moghadam A, Abbaspour-Fard MH, Aghel H, Aghkhani MH, Abedini-Torghabeh J (2014) Enhancement of biogas production by co-digestion of potato pulp with cow manure in a CSTR system. *Appl Biochem Biotechnol* 173:1858–1869
- Santos OCS, Soares AR, Machado FLS, Romanos MTV, Muricy G, Giambiagi-deMarval M, Laport MS (2015) Investigation of biotechnological potential of sponge-associated bacteria collected in Brazilian coast. *Letts Appl Microbiol* 60:140–147
- Sathasivam A, Muthuselvam M, Rajendran R (2010) Antimicrobial activities of cow urine distillate against some clinical pathogens. *Glob J Pharmacol* 4:41–44
- Sawant AA, Hegde NV, Straley BA, Donaldson SC, Love BC, Knabel SJ, Jayarao BM (2007) Antimicrobial-resistant enteric bacteria from dairy cattle. *Appl Environ Microbiol* 73:156–163
- Sharif MR, Alizargar J, Sharif A (2013) Antimicrobial resistance among Gram-negative bacteria isolated from different samples of patients admitted to a University hospital in Kashan, Iran. *Adv Biol Res* 7:199–202
- Sharma CK (2011). Biogas—a boon for India. *Biofuels* 2–3
- Shrivastava S, Mishra A, Pal A (2014) Cow dung—a boon for antimicrobial activity. *Lifesci Leaf* 55:60–63
- Singh D, Fulekar MH (2007) Bioremediation of phenol using microbial consortium in bioreactor. *Innov Rom Food Biotechnol* 1:31–36
- Singh A, Kohli JS (2012) Effect of pollution on common man in India: a legal perspective. *Adv Life Sci Technol* 4:35–41
- Somasundaram E, Amanullah MM, Vaiyapuri K, Thirukkumaran K, Sathyamoorthi K (2007) Influence of organic sources of nutrients on the yield and economics of crops under maize based cropping system. *J Appl Sci Res* 3:1774–1777
- Soni R, Gupta A (2011) Batch biosorption studies of Cr(VI) by using *Zygnema* (Green Algae). *J Chem Pharm Res* 3:950–960
- Stalin V, Perumal K, Stanley Abraham L, Kalaiichelvan PT (2010) Screening and production of subtilin from *Bacillus subtilis* isolated from nutrient-rich organic and biodynamic manures. *IUP J Life Sci* 4:34–44
- Swain MC, Kar S, Padmaja G, Ray RC (2006) Partial characterisation and optimisation of production of extracellular α -amylase from *Bacillus subtilis* isolated from culturable cow dung microflora. *Pol J Microbiol* 55:289–296
- Swain MR, Laxminarayana K, Ray RC (2012) Phosphorus solubilization by thermotolerant *Bacillus subtilis* isolated from cow dung microflora. *Agric Res* 1:273–279
- Teo KC, Teoh SM (2011) Preliminary biological screening of microbes isolated from cow dung in Kampar. *Afr J Biotechnol* 10:1640–1645
- Thajeel AS, Al-Faize MM, Raheem AZ (2013) Adsorption of Pb^{+2} and Zn^{+2} ions from oil wells onto activated carbon produced from rice husk in batch adsorption process. *J Chem Pharm Res* 5:240–250
- The Hindu (2011) About 70 per cent Indians live in rural areas: Census report. <http://www.thehindu.com/news/national/about70percentindiansliveinruralareascensusreport/article2230211.ece>. Accessed 24 Jul 2015
- Thomas KV, Dye C, Schlabach M, Langford KH (2007) Source to sink tracking of selected human pharmaceuticals from two Oslo city hospitals and a wastewater treatment works. *J Environ Monit* 9:1410–1418
- Ullah A, Durrani R, Ullah I, Rafiq M (2012) Antibiotic resistance profile of clinical gram negative bacteria. *J Biol Food Sci Res* 1:23–25
- Umanu G, Nwachukwu SCU, Olasode OK (2013) Effects of cow dung on microbial degradation of motor oil in lagoon water. *GJBB* 2:542–548
- USEIA (2014) Today in India—India is increasingly dependent on imported fossil fuels as demand continues to rise. <http://www.eia.gov/todayinenergy/deatils.cfm?id=17551>. Accessed 07 Apr 2015
- Vakili M, Zwain HM, Rafatullah M, Gholami Z, Mohammadpour R (2015) Potentiality of palm oil biomass with cow dung for compost production. *KSCCE J Civil Eng* 19:1994–1999
- Viikari L, Kantelinen A, Sundquist J, Linko M (1994) Xylanases in bleaching: from an idea to the industry. *FEMS Microbiol Rev* 13:335–350
- Vijayaraghavan P, Vincent SGP (2012) Cow dung as a novel, inexpensive substrate for the production of a halo-tolerant alkaline protease by *Halo-monas* sp. PV1 for eco-friendly applications. *Biochem Eng J* 69:57–60
- Vijayaraghavan P, Vincent SGP (2014) Statistical optimization of fibrinolytic enzyme production by *Pseudoalteromonas* sp. IND11 using cow dung substrate by response surface methodology. *Springerplus* 3:1–10
- Vijayaraghavan P, Vijayan A, Arun A, Jenisha J, Vincent SGP (2012) Cow dung: a potential biomass substrate for the production of detergent-stable dehairing protease by alkaliphilic *Bacillus subtilis* strain VV. *Springerplus* 1:76
- Wachendorf C, Taube F, Wachendorf M (2005) Nitrogen leaching from N-15 labelled cow urine and dung applied to grassland on a sandy soil. *Nutr Cycl Agroecosyst* 73:89–100
- Wang L, Mu G, Tian C, Sun L, Zhou W, Yu P, Yin J, Fu H (2013) Porous graphitic carbon nanosheets derived from cornstarch biomass for advanced supercapacitors. *Chem Sus Chem* 6:880–889
- Wei L, Sevilla M, Fuentes AB, Mokaya R, Yushin G (2011) Hydrothermal carbonization of abundant renewable natural organic chemicals for high-performance supercapacitor electrodes. *Adv Energy Mater* 1:356–361
- Werner U, Stöhr U, Hees N (1989) Biogas plants in animal husbandry. Deutsches Zentrum für Entwicklungstechnologien-GATE
- Wicklow DT (1992) The coprophilous fungal community: and experimental system. In Carrol GC, Wicklow DT (eds) *The fungal community. Its organisation and role in the ecosystem*, 2nd edn. Marcel Dekker, New York
- Wicklow DT, Detroy RW, Jessee BA (1980) Decomposition of lignocellulose by *Cyathus stercoreus* (Schw.) de Toni NRRL 6473, a “white rot” fungus from cattle dung. *Appl Environ Microbiol* 40:169–170
- Wiley MJ, Sherwood ML, Woolverton JC (2008) Prescott, Harley, and Klein’s Microbiology. The McGraw-Hill Higher Education, New York
- Williams KH, Bargar JR, Lloyd JR, Lovley DR (2013) Bioremediation of uranium-contaminated groundwater: a systems approach to subsurface biogeochemistry. *Curr Opin Biotechnol* 24:489–497
- World Health Organization. Report on TBEE. Environmental Health Criteria. International program on chemical safety, 1990
- Wu B, Oesker V, Wiese J, Schmaljohann R, Imhoff JF (2014) Two new antibiotic pyridones produced by a marine fungus, *Trichoderma* sp. strain mf106. *Mar drugs* 12:1208–1219
- Xu B, Hou S, Cao G, Wu F, Yang Y (2012) Sustainable nitrogen-doped porous carbon with high surface areas prepared from gelatin for supercapacitors. *J Mater Chem* 22:19088–19093

- Yadav A, Gupta R, Garg VK (2013) Organic manure production from cow dung and biogas plant slurry by vermicomposting under field conditions. *Int J Recycl Org Waste Agric* 2:21
- Yang DS, Bhattacharjya D, Inamdar S, Park J, Yu JS (2012) Phosphorus-doped ordered mesoporous carbons with different lengths as efficient metal-free electrocatalysts for oxygen reduction reaction in alkaline media. *Am Chem Soc* 134:16127–16130
- Yang DS, Bhattacharjya D, Song MY, Yu JS (2014) Highly efficient metal-free phosphorus-doped platelet ordered mesoporous carbon for electrocatalytic oxygen reduction. *Carbon* 67:736–743
- Zhang X, Sun Y, Bao J, He F, Xu X, Qi S (2012) Phylogenetic survey and antimicrobial activity of culturable microorganisms associated with the South China Sea black coral *Antipathes dichotoma*. *FEMS Microbiol Lett* 33:122–130

Submit your manuscript to a SpringerOpen[®] journal and benefit from:

- ▶ Convenient online submission
- ▶ Rigorous peer review
- ▶ Immediate publication on acceptance
- ▶ Open access: articles freely available online
- ▶ High visibility within the field
- ▶ Retaining the copyright to your article

Submit your next manuscript at ▶ springeropen.com
