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Review Article

Mitigation of Odour in Swine Production Facilities - A Scientific Approach

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Abstract

Animal households can emit significant amounts of aerial pollutants such as odorous compounds and gasses. Swine odour is generated by anaerobic decomposition of manure, feed materials, and wastewater. Management practices such as daily cleaning, ventilation, floor design, drainage and periodic removal of manure are important to reduce odour effects. Airborne pollutants exposed to high concentrations of VOCs (NH3, CH4, H2S, NOx, etc.), dust, and a number of bio-aerosols (bacteria, viruses, endotoxins, parasites, fungi, mycotoxins, etc.) have detrimental effect on the health and wellbeing of both animals and farm worker. There are many technologies available to minimize odour such as dietary modification, liquid-solid separation, bio-filtration, covers for manure storage, and dust suppression. Of all available technologies, it is important for swine farmers to adopt a particular low cost technology for sustainable pig farming in India.

Keywords: Bio-aerosol, Bio-filtration, Livelihood, Odour, Volatile Organic Compound

Introduction

Animal husbandry and dairying as an occupation is a subsidiary of agriculture and is an important livelihood source for small, marginal farmers and landless labourers. Both activities contributed to food security and draught animal power. Besides providing nutritious food to millions of people, they play an important role in generating jobs in the rural sector. India has a huge livestock population that plays a vital role in enhancing rural people's socio-economic status. There are about 302.79 million bovines, 74.26 million sheep, 144.88 million goats and about 9.06 million pigs as per (20th Livestock Census) in the country. Livestock sector share 4.1% to National GDP and 27.4% to total Agriculture GDP at constant prices (BAHS, 2019).

Pig holds an important place among all the livestock species as it is reared by socio-economically poorer sections of society. Because of some inherent features such as high fecundity, improved feed conversion efficiency, early maturity and short generation interval, pigs have great potential to contribute to faster economic returns compared to other livestock species. It has immense potential for the poorer sections of society to ensure food and economic security. Pig rearing in India is very common among the backward and weaker tribal sections of society, especially the North East region (NER). Moreover, pig farming fits very well with the integrated farming and also be complementary to intensive crop production programme (Das and Bujarbaruah, 2005). Increased demand for pork increases livelihood of pig farmers. Pig is considered as the richest source of animal protein at a lower cost (NAP on Pig, 2017).

Contrary to its immense potential, pig production is restricted to some pockets of area like North-eastern states and southern states like Kerala. The total Pigs in the country is 9.06 Million declined by 12.03% over the previous Census (20th Livestock census). Out of 9.06 Million, Exotic/Cross breed population is 1.90 Million and Indigenous/Non descript population is 7.16 Million (DAHD, 2017-18). Cultural taboos in Indian society prevents people to carry out pig production. Also, religious taboo attached with pork consumption is a weakness for which pork marketing is confined to a selective group. In India, low-caste hindus, raise pigs and consume pork (Stevenson, 1954). During traditional ceremony, they slaughter pigs and serve pork in feast (Dhagamwar 2003).

Odour generated in pig production is limiting factor for successful pig farming. Odour generated in swine farm is nuisance for public. Odours in swine farms, many of which not only are responsible for unpleasant odours but also affect the comfort, health, and production efficiency of animals as well as the comfort and health of workers (Lu, 2008; Wing *et al*., 2008: Bibbiani & Russo, 2012). An odour can be defined as a human sensation that occurs when airborne chemical substances, called odorants, stimulate sensory receptors in the nasal cavity (Schiffman *et al.*, 2001). Although odour exposure has been traditionally considered only a nuisance problem, it is now accepted that it can also impair health through direct irritation or psychopathologic mechanisms (Liu *et al.*, 2014). There is also a need to establish stricter regulations for improving the quality of the air in the local livestock facilities (Nicell, 2009). Odours are emitted from manure processing, storage and treatment facilities, as well as from swine houses, especially when manure is kept within houses for more than 4 to 5 days (Riskowski, 2003). While odours may also come from other sources (e.g. from the skin or feed), studies conducted in this sense indicate that animals themselves are less odorous than manure (Kai *et al*., 2006). Swine odours are the human olfactory response to a complex mixture of different odorous gasses (odorants). A large number of odorants have been identified at very low concentrations (Zhang *et al.*, 2002). Assessing and measuring odours has been been a challenging tasks for farmers and researchers. Many technologies have been evolved for reducing odour and odour dispersion models. Some examples are chemical and biological treatment of manure (including manure additives), dietary manipulation, liquid-solid separation, biofiltration, manure storage covers and dust suppression. However, few of these technologies are universally adopted by the swine producers. For this purpose, extensive work to analyze and monitor odours emitted from swine production facilities has been carried out in recent years. This review is aimed to summarize the technologies available to reduce swine odour which is a limiting factor in pig production.

Sources and Constituents of Swine Odour

Sources

Odour emissions are important sources of air pollution from agriculture, livestock production houses, composting plants, food processing industries, dairy factories, wastewater treatment plants, pharmaceutical industries, textile industries, oil refineries, paint finishing plants, chemical industries, and so on (Rappert and Muller, 2005). Over 100 types of odorous gasses are released from composting operations, of which the nitrogen-containing compounds, sulphur-containing compounds and short-chain fatty acids have gained significant attention due to their low threshold limits (Chung, 2007). Within livestock buildings, odours are caused by decomposing protein waste products such as faeces, feces, skin, hair, feed and bedding (O'Neill and Phillips 1991). Primary odour-causing compounds grow from degradable proteins and other nitrogen compounds (Nahm, 2003). Odours emerge from anaerobic decomposition of animal manure into unstable intermediate by-products resulting in a complex mixture of more than 168 volatile compounds (O'Neill and Philli, 2003). Natural biological reactions in pig production houses result in organic acids, aldehydes, alcohols, carbonyls, esters, amines, sulphides, mercaptans, nitrogen heterocycles, aromatics and other gasses that leads to the characteristic odour (Sheridan *et al*., 2002). Odour formation, concentration and emissions from swine facilities depend on many factors, which are summarized in Figure 1.

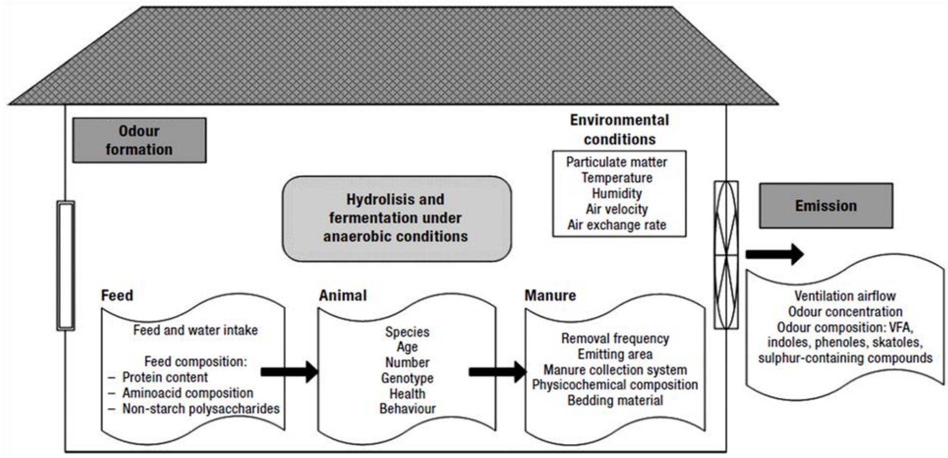

Figure 1: Sources and factors causing odour emission. {Source: Le *et al. (2005)*}

Constituents

Swine odours are composed of a complex mixture of about 330 different odorous compounds, while 110 compounds have been found in dairy facilities (Schiffman *et al*., 2001). Ammonia, hydrogen sulfide, volatile fatty acids, p-cresol, indole, skatole and diacetyl are compounds that cause concern either by their relatively high concentration or by their low detection thresholds (Zhou and Zhang, 2003). Ammonia is, of course, one of the (many) compounds in the air leaving livestock buildings, the combined overall actions of which produce the characteristic odour (Van der Eerden *et al*., 1998). NH_3 formed and emitted from pig buildings may result in poor indoor air quality and seriously affect the atmospheric outdoor environment and natural ecosystems (Mosquera *et al.,* 2005). Typical Volatile Fatty Acids produced are acetic, propionic, butyric, *iso*-butyric, valeric, *iso*-valeric, caproic,and capric acids and their metabolism results in production of CO_2, H_2O (Zhu 2000). Odour contains certain volatile inorganic compounds (VICs) such as dimethyl sulfoxide (DMSO), dimethyl disulphide (DMDS), dimethyl trisulphide (DMTS), limonene, α-pinene, ethylbenzene, benzene, styrene and toluene; amines such as dimethylamine (DMA), trimethylamine (TMA), diethylamine (DEA) and triethylamine (TEA); pyrazine compounds, particularly alkylpyrazines such as DMA; Ammonia is a by-product of low C / N content aerobic composting and contributes to 50% of odours from pig housing and manure storage (Hong and Park, 2005). As NH_3 has a low odour threshold of 4 ppm, human olfactory can easily detect its presence (Ranau *et al.*, 2005). Hydrogen sulphide (H_2S) is of similar concern to NH_3 in households producing pigs which comes from swine manure (Moreno *et al.,* 2010). H_2S is formed by anaerobic degradation of organic compounds containing sulphur (Arogo *et al.,* 2000). H_2S has a low threshold of 1.1 ppb. (Chung *et al*., 2001).

Measurement and Perception of Swine Odour

An odour is a sensation that occurs when an odorant (the chemical that happens to have an odour) influences the sensory receptors in the nasal cavity (Schiffman, 2001). One of the greatest obstacles to the advancement of odour management is the difficulty of measuring odour. The only standardized approach, which is internationally accepted in odour measurement, is the dynamic olfactometry (CEN, 2003). Olfactometry is a psychophysical method for assessing odour concentrations using the human sense of smell, i.e. olfactory senses (Jiang, 2000). In this technique, odour samples are diluted with different, known volumes of a neutral, odourless gas (diluent), e.g., nitrogen or filtered air. A human panelist or group of panelists are presented with the different mixtures of odour and diluent for sniffing, and their responses are registered (Jiang, 2000). It is typical to screen and select panelists based on their sensitivity and consistency. The olfactory-measured odour concentration is expressed as "odour units" (OU) (mostly in North America) or "odour units per cubic meter" (OU / m3) (in Europe). This method uses the dilution-to-threshold principle to calculate odour concentrations but still poses some problems for measurements under field conditions (Smith *et al.* 2007). Olfactometers are only capable of measuring the odour concentration. The electronic nose (e-nose) technology has the potential to measure the odour quality as well as quantity. Research is required to compare human odour perceptions with e-nose measurements, and to develop portable e-noses for field odour measurements (Zhang *et al*., 2002). Sniffing Team Method or plume measurements such as those established by the German VDI 3940 could be more realistic to evaluate the impact of livestock odour (Nicolas *et al.*, 2008).

While a large part of odour emission studies have concentrated on calculating odour emission levels, units used in the literature are not always homogeneous. This heterogeneity and the nature of odour measurements lead to complicating comparisons between studies (Gay *et al.*, 2003). A national standard, or existing standards such as the European Union Standard, should be developed to provide guidelines for conducting odour measurements.

Odour Mitigation Methods

1. Dietary Manipulation

The amount of N and P in livestock manure can be decreased by paying close attention to dietary composition; for example, by applying the principle of ideal protein, by adding synthetic amino acids, by adding various enzymes like phytase, by reducing phosporous content, and by using highly available sources of supplementary P and vitamin D (Nahm, 2000). Reducing crude protein (CP) has been shown to effectively reduce the proportion of excreted nitrogen that is associated with lower ammonia emissions, not only at the housing stage, but also during manure storage (Le *et al.*, 2007). Studies conducted by Kerr *et al*. (2006), showed a decrease of odour concentrations in growing and finishing pigs using low-CP diets with amino acid supplementation. According to Hayes *et al*., 2004; Le *et al*. 2007, feeding pigs with low crude protein diets decreased odour concentration from 30 to 80%. On the other hand, some authors reported that odour concentration and offensiveness increased when low-CP diets supplemented with synthetic amino acids were used (Otto *et al.*, 2003).

Some studies have evidenced the influence of the enteric microbial community on the excretion of odorous substances. O'Shea *et al.* (2011) found that chitosan inclusion in diets inhibited *lactobacilli* populations and this was associated to increased *Enterobacteriaceae* populations and odour emissions from manure. This suggests that lactic-acid bacteria may play an important role in mitigating manure odour emissions. Mc Alpine *et al.* (2012) found that the inclusion of xilanase (an enzyme which degrade beta-xylan intoxylose) effectively reduced manure odour emissions. The use of a protease, however, didn't affect the emissions. Growth-fostering substances also help to reduce pig slurry odour emissions by 53-56 per cent (Nahm, 2002).

The use of fermentable carbohydrates (FC) is effective in reducing the volatilization of ammonia, but may also affect the odour emission profile (Le *et al*., 2005). The increase in feed FC induces microbial activity in the intestine and manure, changing the nitrogen balance from urine to fecal (Clark *et al*., 2005). It has been widely demonstrated that FC incorporated into pig diets increases the volatile fatty acid (VFA) content in manure (Kerr *et al.*, 2006), but it remains unclear whether the odour profile is affected or not. Whereas Lynch et al. (2008) observed an improvement in odour emissions of 41 percent when sugar beet pulp was applied to pig diets, Le *et al.* (2007) found a non-significant effect of FC. The balance between dietary FC and CP plays an important role on odour production and emission Le *et al*. (2008). More research is still needed on the effect sand modes of action of specific microorganisms and enzymes.

2. Odour Reduction in Swine Barn

a. Animal Housing

The manure handling device in-barn plays an important role in controlling odours. To minimize odour generation an effective manure handling system should promote quick separation of manure from animals. Manure deposited on solid flooring because of poor dunging behaviour results in major odour emissions. The drying process of the urine (ammonia production) and the manure is very odourous along with pigs carrying much of the manure on their bodies again contributing to the odour emission (Feddes & Edeogu, 2001). Solid floors prevent the easy separation of manure and urine from animals, causing dirty animals and substantial odour (YCELP, 2002). The best way to reduce the odour associated with solid floors is more frequent cleaning. Daily scraping of manure collected on the pen floor into gutters should be done (Alberta Pork and AAFRD, 2002). To facilitate waste disposal, concrete floors should be sloped toward gutters. Bedding could also be used on the solid floors to minimize odour.

Properly designed slatted flooring systems provide an effective way to distinguish manure from animals (Zhang *et al.*, 2002). Reducing the surface contact between slurry and air in pig processing has been shown to be effective in reducing not only ammonia, but also odour emissions by up to 50 per cent (Ogink & Koerkamp, 2001). Such systems include partial slatted flooring, triangular shaped gutters and regular flushing slurry removal. Slatted floors allowing manure to fall away are less odorous than solid-floored constructions. Partially slatted floors are recommended with approximately one-third slats and two-thirds solid flooring (Alberta Pork and AAFRD, 2002). Slat spacing should be established to ensure that manure does not build-up on too narrow slots, and animal injury does not occur from slats that are too far apart. Proper pen design and selection of slats that clean easily with animal traffic can greatly reduce the pigs contact with manure and reduce manure accumulation. In addition, slats with adequate void to surface ratios are recommended.

b. Manure Storage

Manure storage and treatment is considered a significant source of odour emissions in livestock facilities (Ubeda *et al* 2013). The use of covers to mitigate gaseous emissions has been widely studied in recent years (Vander Zaag *et al.*, 2008). Covers can be classified according to their origin. Covers of natural origin include naturally occurring crusts, straw and other crop residues, woodchips and sawdust, expanded clay, perlite, vegetable oils and aeration foam. Synthetic covers include permeable covers (plastic granules, rubber granules) and impermeable covers such as plastic films. In North Carolina, the predominant collection and holding structure is the earthen lagoon, which is designed for biological treatment and sometimes for biogas collection (Schiffman *et al.,* 2000). Covering such structures can reduce odour and gas releases as well as reduce wind-induced volatilization of gasses. Cheng & Saele (1999) reported that covers reduced odour intensity and irritation by 71% and 91%, respectively. Finally, composite covers combine the best aspects of different materials. The use of covers is desirable when compared with other abatement methods due to their low cost. According to the revision carried out by Vander Zaag *et al.* (2008), the average reduction in the odour of different covers varies from 40 to 90%. Some studies support the idea that covers function as a physical barrier obstructing the free exchange of volatile compounds from the underlying liquid to the atmosphere as the key mechanism for odour reduction. In addition, these findings also suggest that natural coverings can also minimize odours because of the cover bio-filtration action (Hudson *et al*., 2008; Blanes-Vidal *et al*., 2009b).

Odour from deep pit barns as well as barns where the manure is stored are sources of odour (Jacobson *et al*., 1997). One alternative to storage outside is to store manure in deep pits under the slatted barn floors. Earthen manure storage (EMS) is the most common manure storage facility in Manitoba although concrete and steel structures have recently gained some popularity. Earthen manure storage odour emissions are seasonal-very low in winter and more in spring, summer, and fall (Zhang *et al*., 2002).

If manure is stored in the barn beneath the floors, well-designed ventilation systems are needed to provide ventilation in the underfloor pit to minimize odour problems. Establishing proper ventilation flows can also contribute by eliminating the excess of water and reduce odour generation (Ullman *et al.,* 2004). If higher ventilation rates are maintained, drying will result and the odour concentration will decrease. If higher ventilation rates are used during cold weather conditions, the relative humidity will decrease in the barns and dryer conditions will occur producing less odour. Of course, heat that is more supplemental will have to be provided. Research is going on to design a Tee-shaped slat with a coating that reduces the amount of manure sticking to it (Feddes & Edeogu, 2001).

c. Sprinkling Canola Oil

It is well known that airborne dust can cause serious health problems for both humans and animals in pig houses. Different techniques have been used in pig confinement buildings to reduce the dust burdens. For naturally ventilated buildings, where other dust-reduction technologies such as air scrubbers, biofilters and windbreak walls cannot be employed, oil spraying may be the best available solution for odour control (Bibbiani and Russo, 2012). In terms of the dust removal efficiency, oil/water spraying is one of the most efficient dust control techniques for swine buildings. Two Danish systems have been developed over the last ten years and they use a mixture of water and canola oil to control the dust (Lemay, 1999). Godbout *et al*., (2000) applied canola oil about 31 mL/m2/day that resulted in a 90% reduction in respirable dust in swine barn. The dust mass concentration was reduced by 87% using canola oil treatment to the control room and inhalable (>0.5 µm) and respirable (0.5 to 5.0 µm) dust particle counts were lowered by 90 and 86%, respectively (Zhang *et al*., 1996). About 27% hydrogen sulfide and 30% ammonia concentrations reduction were observed with canola oil sprinkling (Lemay *et al*., 2000). The oil film presumably reduced emission rates of gasses into the air, but mechanical and chemical reasons for the gas reduction need to be investigated.

Figure 2: Manual oil sprinkling {Source: Iowa State University, USA (https://www.extension.iastate.edu/ampat/oil-sprinkling)}

3. Bio-filters & Bio-scrubbers

Different techniques have been used to control odour as the air comes out of the building. Bio-filters and bio-scrubbers or wet-scrubbers are some of those technologies used to treat exhaust air from livestock buildings. With a bio-filter, the exhaust air is de-dusted and pushed through an organic material (compost, peat moss, straw or crop residues, wood bark). This bedding material must be humidified and inoculated with a bacterial population. As the exhaust air comes in contact with the bedding material, the bacteria breakdown odorous and chemical compounds present in the air (Revah & Morgan-Sagastume, 2005). These are very effective in eliminating contaminants despite their high investment and operation costs and their characterisation is relatively easy compared to other odour reduction techniques.

The exhaust air from enclosed livestock buildings usually has high concentrations of ammonia, which is volatilized by the degradation of urine and fecal urea and other nitrogen compounds. To remove the ammonia from the air, chemical scrubbers have been designed, which use acid solution. Melse & Ogink (2005) reported an average ammonia removal efficiency of 96%, and remove particulate matter by up to 90%. However, these systems are relatively inefficient to remove odours (typically about 30%) because only soluble compounds are removed, which does not include many odorants (Melse & Ogink, 2005). Recent studies have suggested that the addition of an organic solvent to the water phase could increase the availability of odour components to the bacterial population, enhancing the biodegradation of odour (Melse *et al.*, 2009).

Bio filters, despite the lower ammonia efficiency, are more effective to reduce odours than chemical scrubbers (Melse *et al.*, 2009). Biofiltration is the most effective end-of-pipe technique to reduce odours. Depending on the packaging material, its moisture content and empty bed retention time, the recorded efficiency varies from 80 percent to 99 percent (Chen & Hoff, 2009). Odour was reduced by 91 per cent on average for the 12-inch biofilter and 87 per cent for the 6-inch biofilter (Nicolai and Janni, 1998). Modern type biofilters, referred as closed type, have the ability to regulate flow rate, pH, moisture content, pressure drop, gas conditioning, temperature, oxygen demand, removal of inhibitors (excess of NH_3 and H_2S) and enrichment of nutrients to maintain a proper microbial population for effective filtration (Mc Nevin and Barford, 2000). There has been a lot of advancement in biofiltration technology in recent years, which makes it easier to model a biological filtration process and ultimately design the appropriate biofilter. The designing of the biofilter depends on the type of waste gas and its components, microbial culture, reactor configuration and other such prerequisites (Nanda *et al*., 2012).

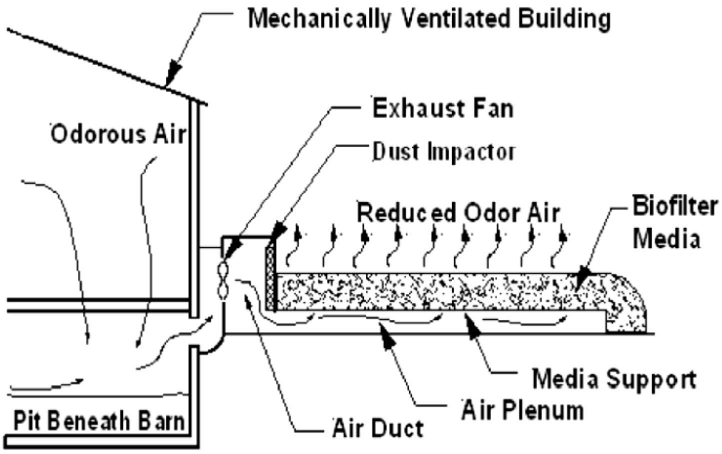

Figure 3: Schematic diagram of open bed biofilter (Nanda *et al.,* 2012)

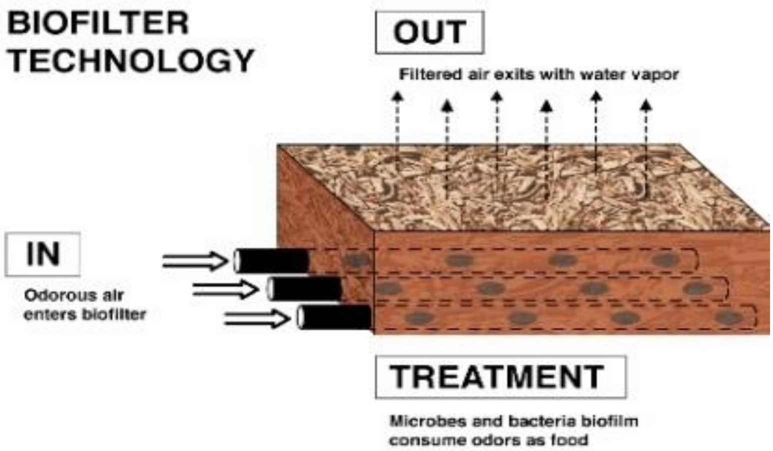

Figure 4: Bio-filter media

4. Shelterbelts / Windbreak / Vegetative Environmental Buffer

Vegetative environment buffers (VEB) and vegetative buffers (i.e. shelterbelts) in particulate tree are a relatively new approach to reducing odours from swine production (Hernandez *et al.,* 2012). Windbreaks and shelterbelts around units of livestock are usually systems of vegetation which redirect wind and reduce wind speed. This effect on wind modifies environmental conditions upwind and downwind sheltered zones, and thus changes the dispersion of odours (Tyndall & Colletti, 2007). Windbreaks not only enhance dispersion by promoting air turbulence, they also serve as a filtration barrier where particulate matter and odours are partly retained. Walls erected downwind from the fans that exhaust air from livestock buildings provide some blockage of the fan airflow in the horizontal direction and reduce the forward momentum of airflow from the fans. This method can reduce the amount of odorous dust transported off the field. (Schiffman *et al*., 2000). That is, windbreaks disperse the airflow from the fans upward so that the odorous airflow becomes more dilute when leaving the farmstead. Objective measures suggest that windbreak walls may reduce irritation by up to 92%. A windbreak positioned near an odour source can reduce the downwind length of the odour dispersion plume (Lin *et al*., 2006). In general, shelterbelts as an odor mitigation technique are both cost effective (Tyndall and Grala, 2009) and environmentally beneficial (Jose, 2009).

Quantifying the odour controlling ability of windbreaks is extremely complicated, and it relies on environment and shelterbelt characteristics. This has been investigated using computational models or scaled wind tunnel experiments (Lin *et al.,* 2009) (Ikeguchi *et al.,* 2003). Odours are best distributed by means of dense and strong windbreaks near the source of odour (Lin *et al.*, 2007). The potential reduction of odour dispersion by windbreaks is apparent and this technique may be recommended to minimize odor nuisances, given its low cost of implementation.

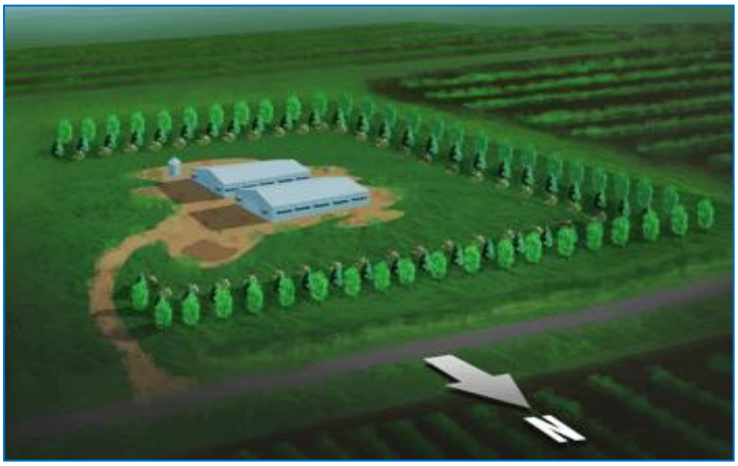

Figure 5: Windbreak around swine farm

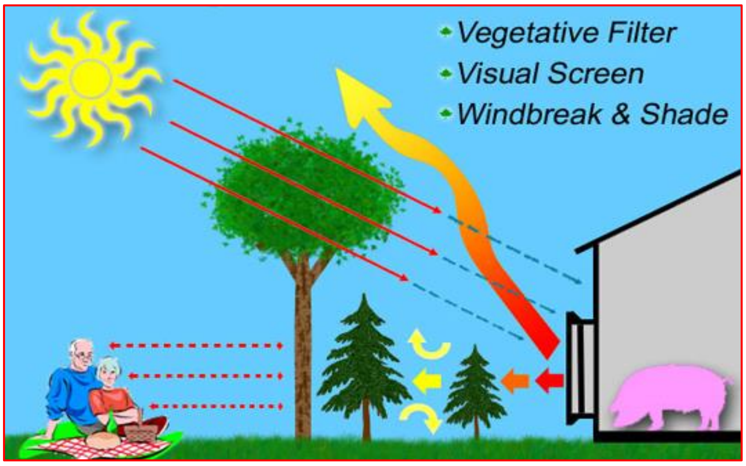

Figure 6: Mechanism of action of Vegetative Environmental Buffer (VEB)

Conclusion

Recent research on livestock odours has significantly improved our knowledge on odour nature, its measurement and mitigation techniques. Biofiltration technology is environmental friendly, has low maintenance cost and higher self-life. It is efficient at ambient atmospheric conditions. It has proved to be a valuable alternative to the physiochemical treatment systems in odour abatement in both developed and developing countries. On the farm level approved odour control techniques are - modified dietary feeding methods, air filters, manure covers, manure management systems and windbreaks. Given this growing awareness of odour abatement techniques, farmers and regulators need a definite commitment to their successful implementation at farm level. Evidence also indicates that odour issues need to be viewed from a global perspective, as odours are released throughout the entire manure management system. Among all technologies available, small and marginal farmers need to implement low-cost technology.

Conflict of Interests

There is no conflict of interest.

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