Reducing Dust in Horse Stables and Transporters

A report for the Rural Industries Research and Development Corporation

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Foreword

Dust is an important airborne pollutant in all forms of animal housing, including horse stables and barns. Although there has been considerable research done in Australia on the air quality within buildings housing pigs and poultry, less attention has been paid to problems within horse stables and transporters.

Dust is not just a nuisance to animals and humans but may precipitate health and performance problems as well. For example, both the prevalence and severity of respiratory diseases, especially conditions such as chronic obstructive pulmonary disease (COPD), appear to be exacerbated by dust, and dust may also aid the spread of other airborne infections.

This publication provides a detailed background to airborne dust problems associated with horse stables and barns, and discusses the sources of dust and the factors influencing the concentration of airborne particles in buildings. The final chapter provides a range of strategies for reducing dust problems that provide stable managers and horse owners with a choice of directions.

This report, the latest addition to our diverse range of over 250 research publications, forms part of our Horses R&D Program which aims to assist in developing the Australian horse industry and enhancing its export potential. It adds to the body of information available to horse owners and trainers and brings together information from a range of technical and scientific sources.

Most of our publications are available for viewing, downloading or purchasing online through our website at www.rirdc.gov.au/pub/cat/contents.html

Peter Core
Managing Director
Rural Industries Research and Development Corporation
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The manager of J. G Goldner Bloodstock Transporters, Somerton Park, South Australia, kindly provided information on horse transporters used in Australia and gave me access to several vehicles.

About the Author

Dr Colin Cargill is a research veterinarian with the South Australian Research and Development Institute on the Roseworthy Campus of the University of Adelaide, He is currently Research Leader of the Pig and Poultry Production Institute (PPPI), which is a joint venture between the South Australian Research and Development Institute, the University of Adelaide and the pig and poultry industries of South Australia.

Together with his colleagues in the PPPI health and housing group, Dr Cargill has written several reviews on both air quality in pig housing facilities and dust and odour problems associated with the broiler industry. The group has developed a range of technologies for measuring and assessing air quality within animal houses, and they have also gained significant expertise in identifying and solving health and performance problems associated with poor air quality.

Dr Cargill is a recognised authority on the effect of the environment on the health and welfare of animals, especially in relation to outbreaks of infectious disease in herds. Before joining the Pig and Poultry Production Institute, he was Chief Veterinary Microbiologist in the Veterinary Division of the Institute of Medical and Veterinary Science, Adelaide and the South Australian Department of Primary Industries, for a period of seven years.
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Executive Summary

1. Background to the problem

Dust is an important airborne pollutant in all forms of animal housing, including horse stables and barns.

The significance of dust in horse transporters has not been investigated, but provided no bedding is used, and horses are removed for feeding, it is unlikely to be a problem.

Although the levels of dust recorded in horse stables are lower than in intensive livestock buildings, the horse is more sensitive to dust than other species and the length of exposure is significantly greater, being measured in years rather than months.

Dust in animal houses is a mixture of organic material including bacteria, bacterial and fungal toxins and spores, gases, urine, dung, undigested feed, pollen and other feed and animal components.

Dust appears to enhance both the prevalence and severity of respiratory diseases, especially conditions such as chronic obstructive pulmonary disease (COPD). It may also aid the spread of other infections.

There is also evidence that inhaled airborne particles reduce the exercise tolerance of clinically normal horses. In other species there is a significant amount of data which indicates that airborne particles engage the immune system, initiating physiological changes resulting in reduced growth and performance.

Dust is mostly measured as mg (airborne dust) per cubic metre of airspace (mg/m³) but can also be measured in terms of particles per cubic metre or particles/ml. The size of the particles varies from less than 0.1 µm to over 100 µm. The important fractions are inhalable dust (less than 10 µm) and respirable dust (less than 5.0 µm).

The levels of dust in Australian stables have received little study, but concentrations of inhalable dust in European stables range from 0.2 to 17.2 mg/m³. The recommended maximum value is probably in the order of 2.5 to 3.0 mg/m³. Concentrations of respirable dust in stables range from 0.15 to 9.28 mg/m³, with a recommended maximum value of 0.23 mg/m³.

The important airborne micro-organisms present in stables and horse boxes appear to be a combination of Actinomycete and fungal spores, although mesophilic bacteria such as Corynebacterium spp and Arthrobacter sp, and gram positive organisms such as Micrococcii spp, have been isolated in significant amounts.

2. The sources and the factors influencing the concentration of airborne particles

The level of airborne particles present in stables is dependent on the relationships between the “sources” and the “sinks” within the building. The sources include the animals and their dung and urine, bedding, feed and incoming air. Bedding, dung and urine are the most significant. The sinks include exhaust ventilation, coagulation, impaction and sedimentation.
Stocking density (in terms of cubic metres of airspace per horse) and building design are also important. The less airspace the higher the level of airborne pollutants.

Temperature and humidity will influence the concentration of viable bacteria, but their effect on other airborne particles is limited. High temperatures reduce concentrations of bacteria whereas high humidity may increase them. Low humidity may result in increased dust levels.

Ventilation rates have a direct effect on dust levels. Increased air movement can dilute the concentration of airborne particles but may also increase re-suspension of particles and delay settling. Exhaust ventilation is a key factor in removing dust, but most ventilation systems are set for temperature control and gas removal, not dust removal.

Bedding is more important than ventilation as a cause of dust. Straw, which is still the most commonly used bedding, is a major source of dust. It also provides a more favourable medium for the growth of fungal and Actinomycete spores than other materials. Alternatives which are less dusty include wood-shavings, shredded or diced paper and commercial synthetic bedding. Straw and paper both promote the growth of fungal spores more effectively than wood-shavings.

The type of feed used is important as hay and similar feeds are extremely dusty. Hay is the main source of the smaller fungal spores found in stable air. These spores may enter bedding and multiply if the bedding is not changed regularly.

Dust may also come from sources that are external to the shed, especially in dusty environments, or in hot, windy and dry conditions

3. Reducing airborne particles in stables

The following strategies need to be considered, and as many as possible adopted into the management of the stable, if dust levels are to be controlled and reduced to a minimum.

Attention to feed

- Soaking hay for 30 minutes reduces respirable dust without excessive loss of nutrients.
- Hay can also be cleaned but using cubes, pellets or ensiled hay is a better strategy.
- Soaked hay produces fewer respirable particles than either lucerne cubes or ensiled hay, and pelleted feed produces fewer smaller particles (less than 2.0 \( \mu m \)) than lucerne cubes.
- Silage prepared from wilted grass is less dusty and has other benefits as well.
- Pellets need to be handled gently as damaged pellets may be dustier than mash.
- Feeding systems where feed is dropped into an open container should be remodelled.

Diet manipulation

- Adding vegetable oils to milled mash or pelleted diets will reduce dust.
- Coating the pellets with vegetable oil after manufacture may be even more effective.
- However, manipulation of diets needs to be planned carefully as feeds that contain certain oils and animal fats may impact on absorption of nutrients from the intestines.

Attention to bedding
• If possible replace straw bedding with wood shavings, diced paper or synthetic material.
• Wood shavings are more resistant to fungal growth than other plant based material.

**Managing and designing the stables**

• Do not store feed or bedding in stables or barns that house horses.
• Store feed and bedding in purpose-built buildings as they create dust every time they are handled.
• Cleaning is an important part of dust reduction strategies.
• Replace bedding frequently, especially if it is soiled and wet.
• Clean boxes and stalls daily and if possible remove the horses during cleaning.
• Industrial vacuum cleaners have been used successfully to reduce dust levels in other forms of animal housing. They may have a place in cleaning the aisles and the walls and ledges of boxes and stables.
• Air cleaning devices and electrostatic filters are not 100% effective and could only be considered for hospital stables where horses with respiratory disease are housed.
• Barns and stables need to be well designed to maximise air exchange rates in still conditions.
• In naturally ventilated buildings air is blown through the building during windy conditions but not when the air is still.
• A minimum of four air changes/hour is required to maintain thermal and hygiene comfort, and a well designed box with the upper door open should always meet these requirements. However, natural ventilation cannot be relied upon solely to control dust problems.
• Mechanical ventilation systems can be designed to reduce dust levels significantly. The key design features are to minimise turbulence and to remove dust particles from around the horse's breathing zone (head height).
• Positive or negative pressure systems that bring air in through a series of holes in the roof and exhaust air at a lower level should control dust and other pollutants effectively.
• The latter would be particularly suited to horse transporters.
• Develop “low dust stables” free of hay and straw, with the floor of the box covered with wood shavings, sometimes placed over a rubber-matting surface. Feed is delivered as pellets from outside the building and the nearest hay or straw is stored at least 50 metres from the building. House horses in individual compartments that have solid floors and walls and external access for feeding. The internal central service corridor is used for cleaning and inspection. Exposed surfaces that collect dust are smooth and cleaned regularly to remove settled dust. Provide sufficient airspace for each horse as this will improve air quality (Table S1).

<table>
<thead>
<tr>
<th>Building type</th>
<th>Airspace/horse</th>
<th>Floorspace/horse</th>
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<tr>
<td>Stables</td>
<td>50 m³</td>
<td>41 m²</td>
</tr>
<tr>
<td>Barns</td>
<td>85 m³</td>
<td>43 m²</td>
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• Minimise horse disturbance and restrict human access to buildings. Dust levels can take several hours to return to previous levels following human and animal disturbance.
• Landscape the surrounds of the building to minimise dust.

**Controlling temperature and humidity**

• Keep the humidity range below 80%.
• Maintain an even, moderate temperature, avoiding fluctuations.

**Other strategies to be considered**

• Fogging, showering and misting in aisles and around the entrance to sheds could be considered. The short-term effects may be dramatic but the long-term effects will be disappointing. There is also a risk of increasing levels of airborne bacterial and fungal elements by increasing the moisture content of the bedding or litter.

• Water and oil mixtures are used in other industries, but these systems need to be adapted and tested before use in the horse industry. Boxes and aisles could be fogged after cleaning, or as an alternative to cleaning walls and internal structures, before returning horses.

• Other technologies such as ionisation and the use of ozone generators have shown little promise but have not been fully tested in the horse industry.

4. **Reducing airborne particles in transporters**

• Few dust problems are associated with transporters providing they are cleaned regularly between trips and feed and bedding are not used.

• Ventilation systems that draw air in at roof level and exhaust it lower down at the rear are designed to control dust and other pollutants in transporters.

• Fogging after cleaning walls, floors and internal structures, or as an alternative to cleaning, prior to reloading the horse, could be considered while horses are in transit.
1. **Introduction and background**

1.1 **The importance of dust**

Dust is an important airborne pollutant in all forms of animal housing, including horse stables and barns. Its significance in horse transporters has not been investigated. Although levels of dust recorded in horse stables are generally much lower than levels recorded in intensive livestock production facilities, the horse appears to be considerably more sensitive to dust than other species of livestock, and the association between dust and respiratory diseases is much stronger (Anon, 1980). Compared to food producing animals, which are slaughtered at three to six months of age, horses are kept in buildings for extended periods over many years, and the length of exposure is significantly greater.

Dust is only one of a number of airborne pollutants which contribute to the quality of air found in buildings housing animals. Air quality within stables and barns is also influenced by a complex interaction between a number of management, engineering and biological factors. In many countries, air quality has become a major concern to intensive livestock producers, as well as production specialists, veterinarians and environmental engineers. In Australia, interest in air quality within intensive livestock buildings, especially pig and poultry production facilities, has increased as a result of studies linking airborne pollutants with reduced growth rates and increased health problems, and their association with odour and other environmental pollution problems (Cargill, 1997). Air quality studies in the horse industry have been mainly confined to the levels of dust and micro-organism in stables and the effects of airborne dust on equine respiratory diseases.

Reports linking poor air quality with reduced production and increased respiratory problems in a range of animal species have come over the last two decades from several countries, including Australia (Cargill and Skirrow, 1997; Clark et al., 1994; Hauser and Folsch, 1993). Although several reports document the relationship between airborne particles and respiratory disease in horses, few deal with the effects of dust on horse performance. In other species there are some preliminary data that indicate that airborne particles engage the immune system, initiating physiological changes in the animal which lead to reduced growth and performance. It has been suggested that the decrease in growth and performance is not only due to reduced appetite and feed intake, but that dietary protein and energy are diverted away from muscle growth to support an activated immune system (Cargill et al., 1997c).

The link between respiratory disease in animals and air quality has been reported in several studies (Donham, 1991; Massabie et al., 1991; Robertson et al., 1990; Webster et al., 1987). In stabled horses, dust associated with fungal spores and thermophilic Actinomycetes is regarded as a risk factor in the development of some chronic pulmonary diseases (McPherson and Thomson, 1983), and that other airborne particulate matter may be reducing the exercise tolerance of horses that appear clinically normal (Webster et al., 1987). Dust may also be involved in the spread of other infections, and it has been suggested that stables need to be at least 100 to 150 metres apart to prevent dust-driven disease spread between buildings (Collins and Algers, 1986).

Dust can also be responsible for equipment failure, especially very fine dust particles that can be responsible for the failure of electrical equipment such as fans. It has also been found that in dusty environments, inflatable polythene ducts used for ventilation need to be at least 12 mm in diameter to avoid eventual blockage (Carpenter, 1986). Ammonia and other gases may hasten the corrosion of equipment and building structures.

Air quality also raises major occupational health and safety concerns for all animal industries where animals are housed. Although it is a greater problem for the intensive livestock industries, such as
pigs and poultry, dust levels above the acceptable maximum exposure concentrations for humans have been recorded in horse stables.

Traditionally, the important pollutants have been identified as dust, especially respirable dust, gases such as ammonia and hydrogen sulphide, and bacteria. However in reality the airspace is filled with a range of bioaerosols from several sources, as well as the gases. These products include bacteria, fungal spores, mycotoxins, microbial proteases, tannins, urine, dander, serum, epithelial cells from the gut, undigested feed, grain mites, pollen and other feed and animal components (Donham, 1995). Various microbial cell components, such as lipopolysaccharide endotoxin from gram negative bacteria, 1,3 beta-glucan from fungi and gram positive bacteria, and peptidoglycan from the cell walls of all bacteria, may also be present (Cargill and Skirrow, 1997).

Dust within horse stables and transporters is important because of its effect on the health and performance of horses, as well as its effect on the health of people working in these environments.

1.2 The effects of dust and bioaerosols on horses and people

The effects of dust are difficult to quantify because of the nature and source of the dust. In most cases the dust will contain other bioaerosols, such as bacteria and endotoxin as well as gases such as ammonia. As stated earlier, reports linking poor air quality with reduced production and increased respiratory problems in a range of species have been published over the last two decades (Cargill and Skirrow, 1997; Cargill et al., 1997b; Hauser and Folsch, 1993).

Several studies have confirmed the link between respiratory disease in animals and air quality within their stables or barns (Donham, 1991; Massabie et al., 1991; Robertson et al., 1990; Webster et al., 1987). In stabled horses, dust associated with fungal spores and thermophilic Actinomycetes is regarded as the cause of chronic obstructive pulmonary disease (COPD) (McPherson and Thomson, 1983). However, although COPD can be a debilitating disease, the condition is manageable and the prevalence is relatively low. In a longitudinal study of respiratory disease in racehorses, it was found that horses housed on straw in loose boxes were twice as likely to develop lower respiratory tract disease, compared with horses housed on shredded paper (Burrel et al., 1996).

As stated earlier, dust may also be involved in the spread of other infections. It has been clearly demonstrated in the poultry industry that dust acts as a reservoir and vector for disease agents such as viruses, as well as being a transport vector for gases such as ammonia, ensuring that these chemicals are inhaled into the lungs and air sacs (Hauser and Folsch, 1993; Morrison et al., 1989). For this reason it is recommended that stables should be 100 to 150 metres apart to prevent the spread of disease agents on dust particles (Collins and Algers, 1986).

Although these reports have documented a relationship between airborne particles and respiratory disease in horses, few reports on the effects of dust on horse performance have been published. Some authors suggest that clinical cases of COPD are probably “the tip of the iceberg” and that other airborne particulate matter may be reducing the exercise tolerance of horses that appear clinically normal (Webster et al., 1987). Lower respiratory tract inflammation also results in poor performance in young athletic horses (Clarke and Madelin, 1987). In other species, however, there are data which indicate that airborne particles engage the immune system, initiating physiological changes in birds and other animals resulting in reduced growth and performance. For example, birds reared in environments free of airborne pollutants grew 25% faster than birds in commercial conditions (Butler and Egan, 1974), and pigs reared in rooms that were cleaned before stocking grew 8% faster than pigs reared in rooms that were not cleaned (Cargill and Banhazi, 1998).

Almost all horses exposed to dust, mites and various fungal and bacterial elements appear to develop antibodies to components within the aerosol. Even young horses exposed briefly on one occasion developed antibodies to mites and moulds, and the researchers suggested that this may result in
allergic attacks later in life (Kamphues, 1996). In earlier studies, several classes of antibodies to airborne aerosols had been detected in 100% of horses tested, but there was little correlation between the severity of respiratory disease and the magnitude of the antibody response (Grunig et al., 1989). However, a correlation does appear to exist between the immune response to airborne microbial antigens and both the type of housing and the concentrations of airborne particles (Madelin et al., 1991).

It is hypothesised that proteins, bacteria, fungi and their cell wall components present in bioaerosols are capable of triggering immune responses and physiological changes in animals and humans. In the case of animals and birds, these may be a reduction in feed intake, as well as a diversion of protein and energy away from the development of muscle to an activated immune system (Klasing and Barnes, 1988; Kelly et al., 1987; Klasing et al., 1987;). Several in vivo and in vitro studies have demonstrated that endotoxins, moulds and organic dust activate the epithelial cells and alveolar macrophages (Robinson, 1994), and that aerosol exposure to endotoxins and 1,3 beta-glucan also modifies the cell population present in the respiratory tract (Fogelmark et al., 1994). Similar findings have been reported in horses after exposure to fungal spores (Clarke and Madelin, 1987). It is also known that a high proportion of airborne “dust” particles present in horse stables are in the respirable range and can be inhaled deep into the lungs (Crichlow et al., 1980). These particles then initiate an allergic or hypersensitivity type immune response in the horse, leading to respiratory and physiological changes in the animal (Eduard et al., 1988).

As mentioned previously, air quality also raises major occupational health and safety concerns for all animal industries where animals are housed and numerous studies have demonstrated the links between dust and human health in buildings housing animals (Donham, 1995). Although it is a greater problem for the intensive livestock industries, dust levels above the acceptable maximum exposure concentrations for humans have been recorded in horse stables. In a review by Donham (Donham, 1995), and in reports from a number of European countries (Cargill, 1996), occupational health and safety issues are regarded as more important than the adverse effects of poor air quality on animal health and livestock production. A survey of 69 full-time poultry stockmen found that although levels of exposure to respirable dust were within occupational health and safety guidelines, 20% were exposed to levels of dust 2.5 times the figure of 10 mg/m³ that is allowed under occupational health and safety guidelines (Whyte et al., 1994). Findings such as these have led to the introduction of strict codes to protect people involved in the intensive livestock industries in several countries including Denmark and Sweden. Guidelines have also been recommended to the Australian pig industry (Jackson and Mahon, 1995).

As most of the dust or airborne particles found within a facility housing horses are generated within the building, it is essential to review the sources of airborne particles before developing strategies for dust reduction within buildings and transporters.

### 1.3 The pollutants

The major non-gaseous airborne pollutants within stables and barns are variously described as airborne particles, dust, respirable dust, aerosols, bioaerosols, viable and non-viable particles, and viable airborne micro-organisms.

Some of these terms are interchangeable and others are not. For the purpose of this review the following definitions are used.

- **Airborne particles** refer to both solid particles and liquid particles of various size.
- **Dust**, or total dust, refers to solid particles ranging in size from less than 1.0 micron (0.1µm) to greater than 100 µm. (1µm = 1/1,000 mm). However, it is mostly made up of particles greater than 10 to 15 µm in size.
• Inhalable particles are solid particles, greater than 10 µm in size and up to about 30 µm, which are deposited in the nasal cavity when inhaled.
• Insparable dust refers to solid particles from 5.0 to 10 µm in size which are filtered out and deposited in the airways of the respiratory tract when inhaled.
• Respirable dust refers to those solid particles less than 5.0 µm in size which are inhaled as far as the small bronchioles, the alveoli within the lungs and air sacs. Once inhaled they absorb moisture, increase in size, and remain trapped in the respiratory system. Particles of less than 1.0 µm are mostly exhaled again.
• Aerosols are airborne particles (solid or liquid) small enough to remain suspended indefinitely.
• Bioaerosols are aerosols containing micro-organisms, their cellular components and metabolic products, along with small particles of dander, dried skin, dried dung (faeces) and other organic particles. They include both viable and non-viable bacteria, fungal particles such as spores, sporangia and hyphae, and bacterial cell wall components such as endotoxins, 1,3 beta-glucan and peptidoglycan, as well as mycotoxins, microbial proteases and tannins. Of particular importance in horseboxes and stables are fungal spores and thermophilic bacteria, especially Actinomycetes.
• Viable particles refer to both liquid and solid particles with a living micro-organism attached, and include clumps of living bacteria as well as bacterial and fungal spores.
• Viable airborne micro-organisms are living organisms capable of dividing and include viable bacteria, fungal elements and spores. The term airborne distinguishes them from micro-organisms attached to surfaces.
• Non-viable particles are sterile liquid or solid particles of either organic or inorganic material.

1.4 Measuring airborne particles, dust and micro-organisms present

The most common method for measuring respirable dust is to trap dust particles on a filter inside a cassella cyclone attached to a vacuum pump operated for three to eight hours at 1.9 litres/minute. A similar method using an open faced filter holder with protective cowl, called an IOM (Institute of Occupational Medicine) attachment, connected to a vacuum pump and operated at two litres/minute is used to measure total dust. Filter papers are dried or conditioned to remove moisture and weighed before and after use.

A second gravimetric method is to allow dust to settle onto a plate or disk and to assess the quantity of dust by weighing or visual assessment.

Realtime particle counters, which are based on electro-optical methods and can be set to measure particles below a certain size (less than 2.5 µm, less than 5 µm and less than 10 µm), can be used to monitor levels of dust over extended periods. This method is particularly useful in studying dust production in relation to the activities of horses and their attendants, such as feeding and cleaning, or in monitoring levels in “before and after” studies when testing the efficacy of dust reducing treatments, such as misting with oil and water.

Gravimetric methods are preferred for research projects or where longterm exposure levels for birds, animals and people are being monitored.

Viable bacteria and fungi can be measured using an Anderson Sampler attached to a vacuum pump. The Anderson Sampler is designed to trap bacterial particles onto plates containing either solid culture media or filters, which trap particles up to a certain size. The samplers have two, five or six stages or levels, with the heaviest and largest particles being deposited onto the first stage and the smallest onto the last stage. Filters are weighed to measure the weight of bioaerosols present and media plates are incubated and the number of bacteria or fungi counted and expressed as colony forming units.
(cfu’s)/cubic metre airspace. Viable airborne bacteria can also be measured using an all-glass impinger.

The total micro-organism load present, both viable and non-viable, can be measured using a nucleopore filtration-elution method. Filters used to trap dust and other bioaerosols are washed and the fluid examined for cells. This method provides an estimate of the total number of bacterial and fungal cells and spores present in the environment, rather than just viable organisms as measured with the Anderson Sampler.

The material collected on dust filters, or special filters designed for the purpose, can be assayed for microbial cell wall components such as endotoxins, 1,3, beta-glucan and peptidoglycan and the concentration present in the airspace calculated (Backstrom and Jolie, 1996).

1.5 Quantifying airborne dust and bioaerosols

Dust is mostly measured as mg (airborne dust) per cubic metre of airspace (mg/m³) (Cargill and Skirrow, 1997) and the dust generation rate is a measure of the amount of dust released into the airspace per hour per animal or kg liveweight of animal. Dust generation rates from horses have not been widely measured but will be greatly influenced by the type of feed and bedding used and the activity of horses and humans.

The concentration of dust in buildings can also be measured in terms of particles per cubic metre or particles/ml. Concentrations ranging from 0.52 to 553 particles/ml have been recorded (Woods et al., 1993; Clarke and Madelin, 1987).
2. **Airborne particles including organic and inorganic dust, bioaerosols and micro-organisms**

The amount of airborne particulate matter present in horse stables will vary in both quantity and particle size, as well as in content. Key factors which influence dust levels include the type of feed and bedding used, horse and human activity, and residual dust levels, especially the amount of dust and friable material on surfaces and floors (Harry, 1978). The largest airborne particles present are approximately 100 µm in size and visible to the naked eye while the smallest particles will be less than 1.0 µm and possibly as small as 0.1 µm in size. The average particle size for airborne dust in a range of barns housing different species of animals has been quoted as between 9.0 and 16 µm (Cargill and Skirrow, 1997) and invisible to the naked eye. Thus, it is possible to have an environment containing large numbers of smaller particles which appears dust free.

Although recommended maximum levels of dust within stables and boxes have been set for humans, maximum levels for horse health and exercise tolerance have not been established. The threshold limit value for humans (TLV) is 10 mg/m³ for inert mineral total dust, and 5.0 mg/m³ for respirable dust (Wathes, 1994). Average levels over a 24 hour period of exposure for humans have been set by some authors as low as 2.4 mg/m³ for total dust and 0.23 mg/m³ for respirable dust (Donham, 1995). It is assumed that levels for animals would be in a similar range, and the recommended levels set for the pig industry are the same as for humans (Cargill and Skirrow, 1997). Levels of fine dust for horse stables in Germany have been set at 4.0 mg/m³ (Zeitler-Feicht, 1993), but the fineness of the dust was not defined.

Dust levels recorded in horse stables and boxes can be divided into total dust and respirable particles of less than 5.0 µm (Tables 1 and 2). In one study where the dust levels in two types of feeding and housing systems were compared, the average levels of total dust in stalls ranged from 0.70 to 2.55 mg/m³, and respirable dust ranged from 0.20 to 0.44 mg/m³ (Woods et al., 1993). However, levels of dust in air samples collected within the breathing range around the horse’s nostrils were much greater and ranged from 0.52 to 17.51 mg/m³ for total dust and from 0.30 to 9.28 mg/m³ for respirable particles. This finding was confirmed by further studies where total dust levels were reported to be up to 3.5 times higher around the horse’s breathing zone than in other parts of the stall (Bartz and Hartung, 1993). However, the differences in respirable dust levels at the two locations were considerably less. Other studies have recorded total dust concentrations from 0.2 to 0.95 mg/m³ (Crichlow et al., 1980), from 0.55 to 3.63 mg/m³ (Sasse et al., 1986), from 0.3 to 7.0 mg/m³ (Matthes, 1980) and around 0.63 mg/m³ (Zeitler, 1985), with daily peaks associated with opening the stables and cleaning and feeding being recorded between 5.00 am and 11.00 am (Crichlow et al., 1980).

In a comparison between conventional stables and “low dust stables”, which are free of hay and straw, levels of dust varied considerably. The concentrations of total dust in conventional stables ranged from 2.19 to 5.48 mg/m³, compared with 0.29 to 2.78 mg/m³ for “low dust stables” and 0.08 to 0.17 mg/m³ in pasture. The figures for respirable dust were 0.44 to 2.20 mg/m³, 0.15 to 0.29 mg/m³, and 0.08 to 0.17 mg/m³ (McGorum et al., 1998).

Dust can also be estimated in terms of the number of particles present within the airspace. In one such study the concentration of airborne particles ranged from 8.8 particles/ml when horses were resting in a box using woodshavings as bedding, to 75.9 particles/ml when horses were being bedded down with straw (Webster et al., 1987). In other studies the figures quoted ranged from 3.11 to 443.85 particles/ml for particles less than 1.0 µm in size, from 19.27 to 553.12 particles/ml for particles less than 2.0 µm in size, from 2.28 to 166.28 particles/ml for particles less than 5.0 µm in size (Raymond et al., 1997; Clarke and Madelin, 1987).

**Table 1: Concentrations of total dust recorded in stables and barns**

<table>
<thead>
<tr>
<th>Range (mg/m³)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.70 – 2.55</td>
<td>In stall</td>
</tr>
</tbody>
</table>
0.52 – 17.51 In horse’s breathing zone
0.20 – 0.95 In barn
0.55 – 3.63 In stall
2.19 – 5.48 Conventional stable
0.29 – 2.78 “Low dust” stable
0.08 – 0.17 In pasture
< 2.40 Recommended

<table>
<thead>
<tr>
<th>Range (mg/m³)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.20 – 0.44</td>
<td>In stall</td>
</tr>
<tr>
<td>0.30 – 9.28</td>
<td>In horse’s breathing zone</td>
</tr>
<tr>
<td>0.44 – 2.20</td>
<td>Conventional stables</td>
</tr>
<tr>
<td>0.15 – 0.29</td>
<td>“Low dust” stables</td>
</tr>
<tr>
<td>0.08 – 0.17</td>
<td>In pasture</td>
</tr>
<tr>
<td>&lt; 0.23</td>
<td>Recommended</td>
</tr>
</tbody>
</table>

The settling pattern varies according to the particle size and weight, with the heavier particles being the first to settle and the last to be resuspended. The still air settling rate for particles around 100 µm is 30cm/second, compared with a settling velocity of 30cm/minute for particles which are around 10 µm in size (Harry, 1978). In still air some particles such as an Actinomycete spore may take up to 30 hours to fall one metre (Clarke, 1994). The proportion of respirable dust (less than 5.0 µm) compared with the total dust will also vary according to air movement and temperature within the shed.

The difference between the total mass of dust per cubic metre and the total number of particles per cubic metre is also an important consideration. Although particles of greater than 3 µm influence the total mass of dust, the majority of particles will be less than 1 µm in size (Carpenter, 1986). It would also appear that the larger non-respirable particles tend to remove smaller respirable particles due to kinematic coagulation (Pickrell et al., 1993).

Although total dust levels have been consistently reported as being highest during the day, respirable dust fractions seem to show little diurnal variation (Zeitler, 1985). Several studies have demonstrated that while respirable particles account for only 15 to 30% of the dust by weight during the day, the respirable dust fraction can account for 32 to 90% of the dust present at night. This confirms that the heavier particles settle out faster during periods of inactivity and rest. However in another study, the relative percentages of respirable and non-respirable particles varied little by weight from day to day. The percentage by weight of respirable particles over a 24 hour period ranged from 32% to 42% on four different days and in four different positions within a stable (Crichlow et al., 1980). The reasons for these different results may depend on other factors. It has been shown that the percentage of respirable particles compared to inspirable particles varies from stable to stable, depending on the design, ventilation and feeding system (Zeitler, 1985).

Particles of concern to horse and human health are often referred to as PM10 (up to 10 µm), PM5 (up to 5 µm) and PM2.5 (up to 2.5 µm) and are in the invisible range. In most species, including the horse, particles of 3.7 to 7 µm are deposited in the anterior portion of the respiratory system, while smaller particles are deposited evenly throughout the rest of the lungs.

2.1 The importance of dust and airborne particles

It is difficult to quantify the importance of airborne dust particles as they vary widely in their make-up. Many dust particles will act as a vector carrying other material adsorbed onto or attached to the
surface of the particle. Gases can react with dust particles or condense onto their surface. Micro-
organisms are either embedded into the dust particle or attached to the surface. Thus, dust particles 
can be true bioaerosols and transport both pathogenic and non-pathogenic microbes, as well as gas, 
deep into the respiratory tract. Although the survival of airborne micro-organisms depends on factors 
such as relative humidity and air temperature, radiation, oxygen content of air and the age of the 
aerosol, when embedded in dust particles they are relatively protected from these forces. When 
embedded in dust, viable infectious micro-organisms can be transferred from stable to stable and it is 
suggested that stables need to be at least 100 to 150 metres apart to reduce the risk of dust driven 
disease spread (Collins and Algers, 1986). While the majority of both viable and non-viable bacteria 
present in the airspace in pig and poultry sheds appear to be attached to the larger particles (Hugh-
Jones et al., 1973), the results of studies in horse stables suggest that most bacterial and fungal 
elements are found amongst the smaller airborne particles present (Woods et al., 1993). Bacterial 
endotoxin present in the air space of livestock sheds also tends to be attached to the smaller particles, 
suggesting that the endotoxin is of faecal origin (Pickrell et al., 1993).

2.2 Airborne microbes

The important airborne micro-organisms present in stables and horse boxes appear to be a 
combination of fungal spores and Actinomycetes (Raymond et al., 1997); when air samples were 
studied under a light microscope, it was found that over 90% of the particles observed were spores of 
these organisms. This appears to be in contrast with intensive livestock houses, where the majority of 
airborne bacteria are gram positive organisms (Skirrow et al., 1995a; Cormier et al., 1990) and by far 
the majority are non pathogens (Cargill and Banhazi, 1996). However, when concentrations of 
mesophilic bacteria have been measured in horse stables, Corynebacterium spp and Arthrobacter spp 
were found to be the dominant species present, more numerous than thermophilic bacteria or gram 
negative organisms. Total mesophilic counts ranged between 26,200 and 150,100 cfu/s/m³ compared 
with 102 to 104 cfu/s/m³ for thermophilic bacteria (Dutkiewicz et al., 1994). On average, only about 
10% of the organisms present in intensive livestock buildings are viable but the situation in horse 
stables does not appear to have been studied. In Australian studies in pig sheds, high levels of 
Streptococci spp have been recovered in air samples from weaner, grower and finisher 
accommodation (Skirrow et al., 1995b) and a close association was demonstrated between the 
concentration of viable streptococcal organisms and the prevalence of respiratory disease. The authors 
were unable to resolve whether the level of streptococcal organisms was an indication of other factors 
which led to respiratory disease, or a direct cause itself. Although Streptococcus zooepidemicus is 
closely associated with lower airway disease in horses (Burrel et al., 1996), most studies in horse 
stables have concentrated on measuring fungal spores and Actinomycetes, rather than Gram positive 
organisms. Where Gram positive organisms have been investigated, Micrococcii spp and not 
Streptococci spp were the dominant species present (Zeitler-Feicht et al., 1992; Zeitler-Feicht et al., 
1988).

Recommended levels for viable airborne bacteria are usually quoted as colony forming units of viable 
organisms (cfu's) per cubic metre of airspace, and a maximum recommended level of 400,000 
cfu's/m³ has been set for horse stables in Germany (Zeitler-Feicht, 1993). This is somewhat higher 
than the level of around 100,000 to 150,000 cfu's/m³ that has been set for the Australian pig and 
poultry industries (Cargill and Skirrow, 1997). However, it needs to be understood that colony 
forming units are a measure of clumps of bacteria, rather than of individual bacteria, and that these 
figures do not include dead or non-viable bacteria. It is also debatable if such values are applicable 
where the majority of micro-organisms are fungal spores and Actinomycetes.

The density of microbial populations in horse stable have been measured in several studies, and in 
most reports indirect methods that rely on organism viability or particle identification have been used. 
It is suggested that culture methods may underestimate the prevalence of spores, and that if dust mites 
are present they may further reduce spore viability. However, reduced viability, or failure of a spore 
to germinate, does not necessarily reduce its effect on the respiratory system (Clarke, 1986).
Endotoxin, 1,3 beta-glucan and peptidoglycan are cell wall components of gram negative bacteria, gram positive bacteria and fungi, and all bacteria respectively. These cell wall components are known to engage the immune system in mammals, initiating physiological changes that appear to result in reduced performance and feed intake (Cargill et al., 1997c). Only the levels of endotoxins in intensive livestock facilities have received serious study, and levels from 10 to 60 times that required to meet occupational health and safety standards have been recorded (Backstrom and Jolie, 1996; Dutkiewicz et al., 1994). In one report, levels of endotoxin in horse stables were found to be generally less than 0.1 µg/m³ (Dutkiewicz et al., 1994), the “cut-off” for OH&S purposes, but in other studies levels were reported ranging from 2.12 to 60.53 µg/m³ in total dust and 0.11 to 19.76 µg/m³ in respirable dust (McGorum et al., 1998). In the latter studies concentrations of airborne endotoxins were considerably higher in conventional stables than in “low dust stables”, which are hay and straw free environments. In the conventional stables levels in total dust samples ranged from 7.52 to 60.53 µg/m³, compared with 2.12 to 17.41 µg/m³ in low dust stables. The concentrations in respirable dust were 1.25 to 11.27 µg/m³ and 0.09 to 0.56 µg/m³ respectively. By comparison, concentrations of endotoxins in a pasture paddock at least 50 metres from the nearest hay ranged from 0.25 to 1.57 µg/m³ and 0.04 to 0.16 µg/m³ respectively. The concentrations of other cell wall components have not been measured in horse stables, but it would be assumed that levels of peptidoglycan would be significant given the numbers of fungal spores and Actinomycetes recorded.

The micro-organisms identified in horse stables include several species of thermotolerant and thermophilic fungi and Actinomycetes, as well as the yeast Candida famata (Clarke and Madelin, 1987). Included in the thermophilic fungi were Paecilomyces variotii, Rhizomucor pusillus and Mucor racemosus, but P. variotii and R. pusillus were the only thermotolerant isolate recorded in significant quantities. Actinomycetes included Saccharomonospora viridus, Micropolyspora faeni, Thermoactinomyces vulgaris and several species of Streptomycin. However, the species probably varies from region to region and from stable to stable depending on the conditions prevailing.

2.3 The sources and factors influencing the concentration of airborne particles

The dust found in horse stables and boxes is almost entirely organic in origin, with the main sources being the horse, its excretions, bedding and feed (Collins and Algers, 1986). As the majority of particles derived from feed are at the larger end of the scale, the horse itself is a major source of respirable dust, with dried faeces, skin, dander and hair being the main sources.

The levels of airborne particles present in stables are dependent on the relationships between the “sources” and the “sinks” within the building (Wathes, 1994). The sources of airborne particles and bioaerosols are the animals and their excretions, bedding and feed, and incoming air, with their bedding and excretions being the most significant. The sinks include exhaust ventilation, coagulation, impaction and sedimentation. As stated earlier, loss of viability or death of micro-organisms may not remove them from the air space and death may contribute to an increase in the level of cell wall components, such as endotoxins, 1,3 beta-glucan and peptidoglycan, that are present (Cargill and Skirrow, 1997).

Horse activity such as stable vices, human activities such as cleaning and feeding, ventilation rates and the air temperature and humidity within the building all influence the dustiness of a stable. Dustiness will also increase as the moisture content of grain decreases and as the size of the particles produced by milling becomes finer. Worn hammers and screens, as well as smaller screens in the range of 2.5 to 3mm, will increase the ratio of finer particles (Robertson, 1992). Although pellets and nibbles are used as part of a strategy to reduce dust, if pellets are friable and feed handling is rough, levels of dust may be higher (Cargill et al., 1995).
The effect of feeding and cleaning

The level of dust within sheds has also been shown to fluctuate from day to day, as well as during the day, with high levels being associated with animal and human activity (Debilquy et al., 1991). The highest levels are associated with sweeping, as well as feeding, catching and moving animals. Concentrations of airborne particles have also been shown to vary over a 24-hour period, according to animal activity. In one study in pig sheds, the concentration of inspirable particles varied from 0.42 mg/m³ at 0400 hours to 2.67 mg/m³ at 12.00 hours (Cargill et al., 1997a). In the few studies where various stable activities have been compared, the particle counts recorded during feeding and cleaning were two to five times greater than when horses were resting (Woods et al., 1993; Webster et al., 1987; Crichlow et al., 1980).

The type of feed used will also influence both the level and composition of airborne particles in the airspace. Hay and similar feeds can be extremely dusty and the concept of “low dust stables” is based on removing both straw and hay from the building (McGorum et al., 1998). Although cleaning lucerne and rye hay will reduce particle counts from over 40,000 particles/mg of material collected to less than 1,000 particles, counts will still be 40 to 50 times higher than those associated with silage (Clarke, 1994). The proportion of fungal and actinomycete particles will also be lower in cleaned hay but will be significantly higher than levels associated with feeding silage and other feed stuffs.

Pelleting feed will also reduce dust levels compared with dry mashies. However, where pellets become damaged the levels of respirable dust may actually be higher (Cargill et al., 1995). Dropping feed into open containers will also increase dust generation.

The effect of stocking density and building design

In intensive livestock production systems there is a strong correlation between stocking density in terms of kg animal/cubic metre and airborne particles and bioaerosols (Cargill and Banhazi, 1996; Wathes, 1994) but the situation with horses is unknown. In intensive animal houses, doubling the airspace has the same effect on airborne bioaerosol levels as increasing air exchange rates from 6 to 30 air changes/hour. In most naturally ventilated buildings it is much easier to reduce stocking density, or increase the volume of airspace per animal, than to increase air exchange (Skirrow et al., 1995a). In a survey of the South African racing industry, it was found that most horses were kept in loose boxes and provided with an average area of 13 m² and an airspace of 55 m³. Many stables were built without consideration of a number of factors that might affect the horse adversely (Lund et al., 1993). A similar survey of horse stables in southern England also found that most horses were housed in loose boxes and were provided with an average area of 12 m² and an airspace volume of 39 m³. On average there were seven horses sharing an airspace and, “on balance, racehorse stables in use to-day are based on designs that are worse overall than the best available in the 19th century” (Jones et al., 1987). The recommended airspace requirements for horses in England are 50 m³/horse in stables and 85 m³/horse in barns (Clarke, 1994). Figures for floor space are 41 m²/horse and 43 m²/horse respectively (Clarke, 1994).

In other species it has been shown that both the number of animals sharing an airspace, and the stocking density in terms of kg animal per cubic metre significantly affect the level of airborne particles, especially respirable dust. For example, the number of pigs, or more correctly the weight of pigs present in the airspace and the number of kg pig per cubic metre, are key factors in the concentration of dust found in sheds (Banhazi et al., 1998; Cargill et al., 1996). However, this information is probably not transferable to horse husbandry where horses are stalled on their own.

It has also been demonstrated that dust levels within buildings are not necessarily constant across or along the shed. Concentrations of dust within the building will vary in different parts of the building according to air flow, and pockets of high levels of respirable dust may be interspersed between high levels of total dust (Barber et al., 1991; Debilquy et al., 1991; Dawson, 1990). In one of the few
studies comparing different locations within stables and stalls, higher concentrations of both total airborne particles and respirable particles were recorded around the horses' head than in the corner or other parts of the stall (Woods et al., 1993). Settling rates may also vary across the stall depending on particle size and air movements.

There is also some suggestion that foals are more likely to be affected by dust in stables than older larger horses. This may be due to the state of maturity of the foal's immune system when exposed to dust, but may also be related to the fact that they are likely to be exposed to greater quantities of dust as they are smaller and continuously inhale air from the zone closest to floor level. Larger horses would tend to inhale air from the zone above the level of the top of the half stable door (Baker pers com, 1998; Woodward pers com, 1998).

**The effect of temperature and humidity**

Both temperature and humidity will influence the concentration of viable bacteria (Butera et al., 1991) but their effect on other airborne particles is limited (Cargill and Banhazi, 1998). High temperatures significantly reduce concentrations of bacteria, but the effect of humidity is more variable. Increased humidity will increase the moisture content in airborne particles and may lead to increased settling rates. Low humidity, as well as very high and low levels of ventilation, result in increased dust levels (Pedersen, 1993).

**The effect of ventilation and air movement**

Ventilation rates have a direct effect on dust levels through increased air movement, which increases re-suspension of particles and delays settling. However, exhaust ventilation is a key factor in removing dust and its benefits should not be overlooked. The key problem is that most ventilation systems are set for temperature control and hence too low to affect dust levels (Robertson, 1992). Ventilation can play a significant role in controlling the level of pollution in stables, and the rate of air exchange has been shown to have a major influence on the air quality in stables (Webster et al., 1987). However, it would seem that under many conditions natural ventilation cannot be relied upon to provide satisfactory air quality within the building (Dunlea and Dodd, 1995). The so called American-type barns, which are naturally ventilated buildings with smaller openings, certainly provide inadequate ventilation rates (Wathes, 1989). On the other hand, a well designed box with the upper door open should always meet the thermal and hygiene comfort requirements of the horse and in still air the ventilation rate should always exceed the minimum of 4 air changes/hour required (Webster et al., 1987). Although not all barns have adequate ventilation, the type of bedding used, and whether or not feeding is in progress, are more important factors than ventilation in determining air quality. In a study of naturally ventilated stables in South Africa, the ventilation rate in periods of calm winds was approximately 7.0 air changes per hour, compared with 2.2 changes/hour with doors and shutters closed (Lund et al., 1993). In a similar study in England the ventilation rate in calm winds, with the top stable door open, was 6.6 air changes per hour, compared with 2.2 air changes with the door closed (Jones et al., 1987). Hence it is important that the top door remain open, especially in calm conditions.

Natural ventilation is based on the stack effect, ie as warm air rises from the bedding and the horse, it is exhausted through high level vents and fresh air is drawn in through low level openings. Hence capped ridge vents or breathing rooves are helpful in maintaining adequate air exchange rates in naturally ventilated barns (Clarke, 1994). While gas may be removed efficiently by natural ventilation, the ability of such systems to remove dust is relatively poor unless a strong updraught is developed inside the building. There is a tendency for particles to be held in suspension without being removed (Cargill and Skirrow, 1997).

Dust concentrations are also influenced by air movement patterns. Air current speeds of around 0.15 m/sec are sufficient to initiate and disperse dust generated from the stock themselves. However,
ventilation will increase the air movement velocity and hence re-suspend settled dust. Animals also influence the airflow patterns in sheds by their movement and the fact that they form a solid mass in the path of the air (Smith et al., 1993). Disturbing a resting horse will increase the dispersal of dust generated by the animal as well as increasing re-suspension of settled dust.

**The effect of bedding**

According to a number of surveys (Dunlea and Dodd, 1997; Jones et al., 1987; Lund et al., 1993; Webster et al., 1987) straw is still the most common type of bedding used in the horse industry. This is despite evidence from a number of studies which confirms that straw is a major source of dust and also provides a more favourable medium for the growth of fungi and Actinomycetes (McGorum et al., 1998). Other types of bedding that have been studied in relation to dust and airborne particles include wood-shavings, shredded or diced paper and commercial synthetic beddings (Clarke, 1994). Fresh diced paper and wood shavings were found to contain few spores, whereas wheat and barley straw contained moderate numbers of fungal spores, especially *Alternaria* species, but few of the smaller fungal spores. Hay appears to be the most usual source of the smaller fungal spores found in stable air, but the spores may enter bedding and multiply if the bedding is not changed regularly (Webster et al., 1987). It was also reported that the growth of the fungal spores, once lodged in bedding, was more rapid in straw and paper than wood-shavings, and that higher levels of airborne respirable dust or particles were observed where soiled bedding had been removed, but spilt hay allowed to accumulate. Warmth and high humidity, caused by poor ventilation, also contributed to high levels of airborne particles, probably as a result of increased microbial activity (Webster et al., 1987). A more recent study also confirmed that wood-shavings produce less dust than either straw or shredded paper (Dunlea and Dodd, 1996), but other studies have demonstrated that diced newspaper and synthetic bedding materials generate fewer airborne particles, especially micro-organisms, than other material (Clarke, 1994).

**The effect of external sources of dust**

Dust may also come from sources that are external to the shed, especially in dusty environments, or in hot, windy and dry conditions. In stable complexes which contain a feed mill and feed storage facilities, under some conditions the levels of dust in the air entering the stables may be higher than within the stables (Dunlea and Dodd, 1995). Although external sources may account for only a small fraction of the airborne dust within the shed, attention needs to be paid to the design of the complex as well as to landscaping the area around buildings to minimise dust generation.
3. Controlling and reducing airborne particles in stables and transporters

It is essential to know the organic composition of the dust and airborne particles present in a stable or transporter so that the source of the dust can be determined. Knowing its source is an important part of any strategy aimed at reducing dust. If the source of the dust is not apparent, or its composition is unknown, this will need to be determined before developing strategies to reduce airborne pollution.

3.1 Handling feed to reduce dust

Feed is one of the major sources of airborne particulate matter in stables and several strategies have been tested to reduce dust generation from feed. Soaking hay for periods from 30 minutes to 12 hours will reduce the concentration of airborne respirable particles by up to 90%, but it will also reduce the magnesium, sodium, phosphorus and potassium content of the hay. Although soaking hay for 30 minutes appears sufficient to reduce respirable particles without excessive loss of nutrients (Moore-Colyer, 1996), it may be possible to use a shorter soaking period to reduce dust without any loss of nutrients.

The dust generated by feeding dry and soaked lucerne hay, lucerne cubes, pelleted diets and an ensiled hay product have also been compared (Raymond et al., 1997). While dry hay produced significantly more dust that any other feed, soaked hay produced fewer respirable particles than either lucerne cubes or ensiled hay. Pelleted feed also produced fewer small particles (less than 2.0 µm in size) than lucerne cubes. In a further study, it was found that silage prepared from wilted grass generated significantly fewer airborne particles and had other positive outcomes as well. The silage, when fed at about 50% dry weight for three months, eliminated digestive disorders in horses weighing 550 kg fed at 4.0 kg twice daily (Vandenput and Lekeux, 1996).

Automated enclosed feeding systems, which deliver undamaged pelleted feed, will also reduce the dust level significantly. However, this is not considered to be a practical solution for the horse industry. It may also fail as in some automated feeding systems pellets are damaged in transit, resulting in dust levels which are higher than in sheds feeding unpelleted diets (Cargill et al., 1995). Feeding systems in which feed is dropped any distance into an open container should be remodelled to avoid dust.

Although the manipulation of diets has been investigated as a means of reducing airborne pollution in the major intensive livestock industries, few reports of diet manipulation in the horse industry were found.

The addition of tallow and vegetable oils to feed has been used to reduce dust levels in the pig and poultry industries (Dawson, 1990), and oil is already widely used in horse diets, especially for horses participating in endurance rides and those prone to glycogen storage disorders (Woodward pers com, 1998). Soybean oil has been found to be more effective than animal fat, and feed ingredients such as corn are less dusty than wheat and other grains (Heber and Martin, 1998). Coating pellets with soybean oil or fat will also reduce dust levels by up to 85% (Li et al, 1996). In one study, less than 3% of the dust particles generated from fat coated pellets were larger than 5.0 µm (over 97% were in the 0.5 to 5.0 µm range) compared with to 24 to 40% for non-fat coated pellets (Li et al., 1996).

Canola oil has also been used as a dietary additive to reduce total dust, but it was found to have little effect on reducing the number of smaller respirable particles (Welford et al., 1990). Spraying feed with canola oil also appeared to reduce total dust but resulted in higher levels of respirable dust (Welford et al., 1990). However, manipulating diets needs to be planned carefully, as feeds which
contain certain oils and animal fats may impact on absorption of nutrients from the intestines (Anon, 1992).

3.2 Handling bedding to reduce dust

Bedding is also a major source of airborne pollution in all forms of animal housing. Several studies have shown that straw is a major source of dust, especially if horses are being fed hay. Replacing straw bedding with wood shavings, diced paper or synthetic material will result in lower airborne particle counts in stables, especially when used in conjunction with pelleted feed (Clarke and Madelin, 1987; Thomson and McPherson, 1984). Wood shavings have also proven to be more resistant to fungal growth than other plant based material such as paper, except in deep litter systems (Clarke and Madelin, 1987).

It is also important to store feed, fresh bedding and other materials in other buildings, where animals are not housed, or in rooms with an independent airspace and ventilation system (Woods et al., 1993). Including feed mills in horse stable complexes is not recommended, as it makes it more difficult to reduce dust levels within the buildings (Dunlea and Dodd, 1997).

3.3 Cleaning to reduce dust

Cleaning is an important part of dust reduction strategies. Frequent replacement of bedding, especially when it is soiled and wet, will reduce the rate of production of airborne particles, as the growth of several fungal species, especially *Mucor racemosus*, is facilitated and enhanced by the presence of dung and moisture (Clarke and Madelin, 1987). Cleaning the facilities while horses are in-situ is not recommended as the concentration of airborne particles will be highest while bedding is being removed. Boxes and stalls should be cleaned daily and horses should be removed from the area and the ventilation maximised during this period. Industrial vacuum cleaners, which have been used successfully to reduce dust levels in other forms of animal housing, may have a place in cleaning stables, especially alleyways and the walls of boxes and stables.

Where the level of airborne particles present during non-cleaning periods is higher than recommended and ventilation rates cannot be increased, or in the case of horses with COPD or allergic reactions to bioaerosols, systems can be developed which either clean air or reduce dust generation on a continual basis. Cleaning the air requires an internal recirculating device, the effectiveness of which will depend on its capacity and air throughput, the size range of particles removed and its location within the building. Air filtration systems have been used in other animal industries, but these are difficult to assemble and operate in naturally ventilated sheds. Electrostatic filters with a relatively small capacity and filtering 0.5 m³ air/second have also been used. While they remove 80% of the bacteria and 90% of the total mass of airborne dust, along with almost all of the particles larger than 8.0 µm in size, less than 50% of particles below 3.0 µm are removed (Carpenter, 1986). Hence, many fungal spores in the respirable particle range will remain.

Most internal air cleaning devices consist of particulate air filters, and some include odour adsorbing material as well. Originally soil was used, but it is less effective than plant material such as peat and plant compost (Hoff et al., 1997). Whether cleaning air has any effect on the health of animals is not clear. The results of studies in calf barns suggest that an air recirculation rate of three times the ventilation rate is required before calf health is improved (Carpenter, 1982). In poultry and pig facilities, where ventilation systems are used to control temperature rather than dilute pollutants, a recirculation rate equal to the maximum ventilation rate is a good compromise between cost and dust reduction (Carpenter, 1982). However, this is likely to be close to the limit of practical feasibility in existing buildings (Carpenter, 1986).
3.4 Using ventilation to reduce dust

Using ventilation to remove dust is more complex and less effective than using it to remove gas or control temperature. Most ventilation rates are set for temperature control and the removal of carbon dioxide and are inadequate for dust removal. The ventilation system needs to create minimal turbulence and aim to remove dust particles from around the horse's breathing zone (head height). In general, negative ventilation systems that draw air upward and out through roof vents, or vents high on the wall, tend to keep larger particles in suspension without removing them. Positive or negative pressure systems which bring air in through the roof, especially through a series of holes in porous ceilings, and exhaust air at a lower level are designed to overcome this problem (Dunlea and Dodd, 1996; King and Spencer, 1973). Such a system has been shown to work efficiently within a stable complex (Dunlea and Dodd, 1997) but it should also work well in a horse transporter as air could be dragged through from ceiling height at the front of the vehicle and exhausted at floor level at the rear of the vehicle. Maintaining uni-directional flow in a stationary vehicle or a building is more difficult as the air pressure inside the building must be sufficient to prevent backflow of air through outlets exposed to high wind velocities (Harry, 1978). Hence, air outlets need to be protected from prevailing winds.

The above system has been used to solve a problem in a stable where an external source of dust was found to be the cause of high levels of respirable dust. A mechanical ventilation system was designed so that air entered the building through a perforated ceiling and was removed via exhaust fans located on the side walls near the floor. The incoming air was filtered through a bag and levels of respirable dust were reduced from 45 particles/ml in incoming air to less than 10 particles/ml in the air within the stable (Dunlea and Dodd, 1996). Dust created within the building by tossing and agitating bedding was removed within 12 minutes by the system (Dunlea and Dodd, 1996).

Underfloor ventilation systems have been used in intensive livestock buildings to move air into underfloor pits and trap particles in liquid, thus removing them from exhausted air into treatment in lagoons. However, such systems would be difficult to adapt to the horse industry.

3.5 Using building design to reduce dust

The design of a building and the type of ventilation used can also affect the movement of airborne particles (Wynne et al., 1995). In one major study (Webster et al., 1987), it was found that ventilation rates were generally satisfactory in individual boxes but not in barns. Most buildings were naturally ventilated and ventilation was achieved by holes in the roof and/or walls. During windy conditions air is blown through the building but in still air, ventilation is achieved by temperature gradients resulting in the development of natural convection currents. In a dusty environment of 300 to 600 particles/ml, it would require from 11 to 22 air changes/hour to reduce the particle count to an acceptable level. This may be achieved on a regular basis in a box with the top half of the door open (Lund et al., 1993; Jones et al., 1987;) but is rarely achieved in a larger building. Buildings with sidewall ventilation have the capacity to move large amounts of air and dilute the concentration of particles within the shed as well as in exhausted air. Slowing ventilation to increase moisture and temperature will increase the concentration of particles, and although when ventilation is subsequently increased dust levels will be reduced, it may take some time for an acceptable level to be achieved. If dust levels are to be controlled using ventilation, it is important to maintain a constant rate of ventilation, especially in winter (Wynne et al., 1995).

In order to maintain good air hygiene, it has also been recommended that horses should have individual compartments with solid floors and walls and have external access for feeding but an internal central service for cleaning and inspection (Krawiecki, 1995). So called "low dust stables", 
which are free of hay and straw, are also recommended (McGorum et al., 1998). The floor of the box is covered with wood shavings, sometimes over a rubber matting surface, and feed is delivered as pellets (Woods et al., 1993). The nearest hay or straw is stored at least 50 metres from the building (McGorum et al., 1998).

Ensuring that any exposed surfaces that collect dust are smooth will also assist in reducing the amount of re-suspension that occurs. As all surfaces contain a boundary layer about 1.0 mm deep, which results from surface air friction, it requires an air current greater than normally present in barns to dislodge particles of more than 30\(\mu\)m in size. On smooth surfaces the dust can be held within the boundary layer until cleaning occurs, but on roughened surfaces the dust is more likely to project beyond the boundary layer and will be resuspended by localised air movement. Hence, insulation or any other material that has a roughened surface will increase the generation rate of dust through aiding re-suspension of settled material.

Providing sufficient airspace for animals is also an important factor in providing a good physical environment and good air hygiene (Cargill and Banhazi, 1998; Cargill and Banhazi, 1997). The recommended airspace requirements for horses in England are 50 m\(^3\)/horse in stables and 85 m\(^3\)/horse in barns (Clarke, 1994). Figures for floor space are 41 m\(^2\)/horse and 43 m\(^2\)/horse respectively (Clarke, 1994). Reducing the stocking density in terms of kg animal/m\(^3\) is an essential part of improving air quality within livestock houses (Wathes, 1994).

As dust levels can take several hours to return to previous levels following human and animal disturbance (Cargill, unpublished), minimising the disturbance of stalled horses and restricting human access to buildings must be part of any management strategy aimed at dust reduction.

### 3.6 Managing humidity and temperature to reduce dust

Humidity has two effects on airborne dust. It affects dust generation and it affects the viability of airborne microbial contaminants. High humidity within the stable may also facilitate the growth of moulds and increase airborne particle counts. It is also clear that the range of organisms found will vary between temperate and warmer climates. Airborne dust increases when the humidity falls below 60\%, especially at lower temperatures. Increasing humidity tends to increase the weight of dust particles through increasing the moisture content, as well as promoting clumping. Both of these changes result in increased settling rates. However, increased humidity is also associated with condensation and reduced animal comfort. As bacterial cells tend to die as they dry out, the viability of bacteria is reduced as the humidity decreases and the air becomes drier. However, once they are dry or form spores they can remain viable for long periods. As an example, \(E\ coli\) has been shown to remain viable in dry dust for as long as 32 weeks. Temperature will also influence the viability of micro-organisms associated with dust, and generally viability decreases as temperature increases. For all of these reasons the compromise reached is to set optimal humidity range at a maximum of 80\% (Harry, 1978).

Fogging, showering and misting sheds with water have all been used to reduce dust in intensive livestock production. Although some dramatic effects have been seen in reducing total dust, little effect on respirable dust has been reported (Ryhr-Andersson, 1990) and the longterm effect has been disappointing. There also is a risk of increasing levels of airborne bacterial and fungal elements by increasing the moisture content of the bedding or litter (Anon, 1992).

Water and oil mixtures are being used in the pig industry and feed manufacturing industry to reduce dust levels in sheds (Takai et al., 1995; Gustafsson, 1994; Lai et al., 1984). Both a high pressure system and a low pressure system have been used in Denmark. The low pressure system requires an emollient and can be operated from an existing sprinkler system with modified nozzles. The oil is added with an emollient into the water line via an automatic dosing system at a rate of 3 gram
oil/pig/day. Pigs and rooms are sprayed 5 to 10 times per day for 20 to 30 seconds each time (Anon, 1994). Danish pig producers use canola oil, but other oils are being tested in Australia. The recommended pressure varies depending on the temperature, but a pressure of 30 psi appears to be satisfactory under most conditions. The high pressure system requires special equipment and is under patent to a Danish company and on current costs cannot be considered by Australian industries. A similar system, which sprinkles the shed with vegetable oil only, at a rate of 5 to 20 ml/square metre of floor space/day, has been developed in Canada (Zhang, 1996), where applications of oil onto the floor have also been used (Perkins and Feddes, 1996). Such systems can be adapted for use in a range of buildings and could prove beneficial in the horse industry. Boxes and transporters could be fogged either after cleaning, or as an alternative to cleaning walls and internal structures and washing floors, prior to returning or loading the horse.

3.7 Using other technologies to reduce dust

Ionisation of the airspace has been found to increase the rate of dust deposition in sheds (Enache and Andrisan, 1990), but the method has not been widely examined under commercial production methods. In one study, the use of an air ioniser in a stable was found to have no effect on the cellular respiratory responses of horses, but air hygiene was not examined (Fogarty et al., 1990). Other reports suggest that although ionisers enhance the killing of bacteria they are of little value in reducing dust levels (Clarke, 1994).

Ozone generators have been used to reduce bacterial levels within buildings in the chicken industry and are being investigated in the pig industry (Middleton, 1998). Depending on outcomes from these technologies in the intensive industries, they could provide alternative solutions for reducing the concentration of bacterial and fungal elements in stables.
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