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PM in and from agriculture - introduction and overview

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PM in and from agriculture – introduction and overview

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Introduction

Agriculture and the environment are connected and interacting in a more sophisticated way than normally worked out in the chain emission-transmission to exposure and effects. Agriculture is source of various materials which may affect all compartments of the environment - air, water, soil, plants and individuals. But agriculture is acceptor of many pollutants from different sources of the environment, too. At least agricultural areas are the environment e.g. for animals or human beings which use the fields, forests and fruit gardens for resting and recreation.

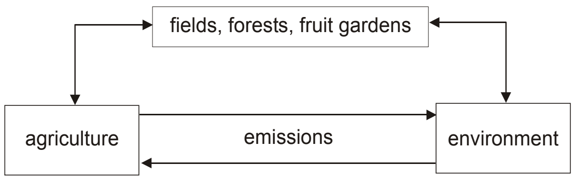

Figure 1:
Interaction between agriculture and environment

In the past mainly ammonia emissions and means for reduction have been discussed on nearly all levels of research, administration and legislation. Particulate matter (PM) - aerosols and dust - had been seen as a more secondary problem for health and welfare of man and animal. But newer more comprehensive knowledge shows that the effects of particles on individuals had been underestimated. Therefore limitations of PM found entrance into national and European regulations /1/.

In the following, sources and effects, transport models and measurements of PM in and from agriculture will be discussed under consideration of particle size and the composition of the sometimes very complex bio-aerosols.

Keywords: particulate matter (PM), bioaerosol, sources, emission, air quality, measurements

Definitions

Particles in air pollution and control require definitions concerning size and material which must be considered for measurements, transport and effects.

In the past particle size was distinguished as total dust or the respirable fraction according to the convention of Johannisburg /2/. Meanwhile new definitions are valid e.g. ISO 7708 defines health related particle size fractions, cf. figure 2 /3/. Inhalable, thoracic and respirable fractions are derived from the depth of entrance into the human breathing tract. Concerning ambient air US EPA defined PM10 and PM2.5 /4/. PM means particulate matter and the index numbers 10 and 2.5 are the cut-off diameters of particle separators that the total suspended particulates (TSP) have to pass. PM definitions are quite close to the health related fractions. Looking to the effects, ultrafine particles PM0.1 become more and more important.

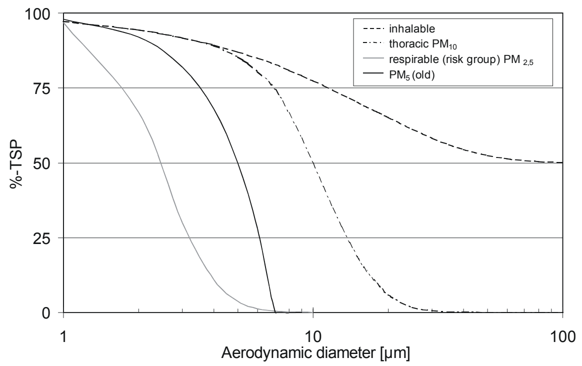

Figure 2:
Fractions of particles acc. to EN ISO 7708

The definitions above are only particle size related without any consideration of substances and materials. Particle dispersions from agriculture are composed by various matter of different origin. These bioaerosols consist of anorganic matter e.g. from soil, organic matter from plants or animals as well as dead and alive microorganism like germs, fungi, viruses, bacteria or parts of these e.g. endotoxins. This definition of bioaerosols doesn't reflect to particle size in a particular way.

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Sources

Certain operations and the use of materials like fuels, fertilizer, pesticides and animals' food and litter result in the emission of dusts inside buildings and outside in fields. In contrast to other commercial plants, emissions from agriculture are discontinuous with different frames of time. In plant production, the emissions depend on the stage of the fruit - seeding, growing, harvesting and soil cultivation. In animal production, the life cycle and kind of production of the different species has to be considered – dairy cows, fattening pigs, broiler and laying hens.

Figure 3 shows possible anthropogenic sources of dust produced by agriculture in plant (food and non-food) and animal production. There are stationary and mobile sources. Examples of stationary plant production systems are systems for cleaning and drying and for unloading, sorting and sacking the raw and final products. In animal production, the animals themselves produce particulates of organic materials e.g. from skin and feathers. Other sources of dust inside an animal house are the result of feeding, stocking and manure management. Emissions caused by combustion for heating the animal house can be calculated by specific emission factors and the consumption. NH_3 emissions are the origin of secondary fine particles, which may be part of long range transport /5/.

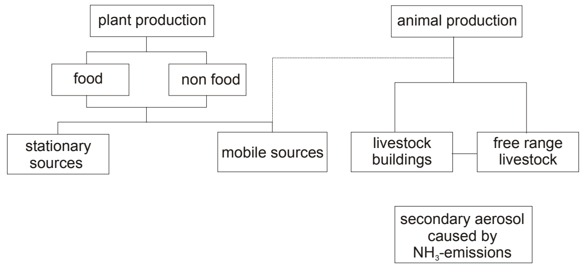


Figure 3:
PM-Sources of agriculture

Most mobile sources are associated with plant production although the transport and the application of organic fertilizers may be seen as part of animal production. Self-propelled farm vehicles e.g. combine – harvesters and tractors with mounted machines for soil cultivation, harvesting or spreading fertilizer or pesticides produce emissions of dusts in the fields. Particle emissions from the engines' exhaust can be calculated by fuel consumption and specific emission factors which depend on the kind of fuel and engine. In the international szenario of air pollution and control e.g. LRTAP (Longe Range Transboundary Air Pollution) these emissions are not considered specifically as part of agriculture but will be mentioned in the sectors of on and off road traffic /6/. Nevertheless these problems are subjects of agricultural engineering research /7/. Relevant sources agreed for consideration in the UN ECE Task Force for Emission Inventory and Projections are given in table 1.

Table 1:
PM sources of agriculture – UNECE-Activities

Plant production	**Feed management on the farm**	**Housed Livestock**
Harvesting	Milling	Dairy cows
Post-Harvest treatment	Mixing	Other cattle
Soil cultivation	Blowing	Fattening pigs (incl. Weaners)
Fertilizer application	Conveying	Sows
	Delivering in troughs	Ovines
	Handling the raw material	Horses
	Pellet-Making	Laying hens
	Blowing of materials delivered to the farm	Broilers
		Other poultry
		Fur animals
On field burning of stubble, straw …	**Nature**	**Free range livestock**

Measuring techniques

Depending on the task PM measurements require different instrumentation. PM emissions of forced-ventilated livestock buildings or capsulated plants for drying and cleaning cereals or greenfodder require isokinetic samples mostly combined with the gravimetric method according to VDI 2066 /8/.

Aim of isokinetic sampling is to get a representative collection of TSP. If information about special fractions are wanted e.g. for estimation of the content of fine particles for dispersion models or to design particle separators for emission reduction, particle size analysis is carried out e.g. using the Coulter Counter Technique or directly measured using a pre-separator with a known fractional collection efficiency curve.

For measuring air quality inside buildings a discontinuous gravimetric method is used if further analyses of dust material are wanted e.g. for microorganism and endotoxins. A quasi-online dust monitor is used if short time events must be detected over a day.

Health related samples are taken according to the convention of Johannisburg in which the respirable fraction is calculated the following penetration function:

$$P = 1-(d/d_0)^2 \quad d_0=7.07\mu m \quad \text{aerodynamic diameter}$$

Depending on the new conventions and regulations other particle size sensitive measuring techniques are developed. In principle, the following different ways of measurement are possible, cf. table 2.

Optical instrumentation is particle size sensitive but difficulties arise due to the composition of agricultural dusts. They are not homogenous in physical or optical density and are heterogeneous in shape as shown in figure 4 for a typical dust from a poultry house.

Figure 4:
Photomicrograph of dust from a poultry house, showing its heterogeneous nature

Thus optical instruments must be calibrated for the particular dust which is to be measured. The gravimetric method is used to provide the reference for the calibration /9/. Figure 5 shows the reading of an optical instrumentation versus dust concentration in a barn.

Table 2:
Particle size-selective measurements

Aerodynamic separation	Conventional filter weighing
	Online electronic balance
	Online optical detection
Sampling total dust	Online size selective optical detection
	Conventional filter weighing with additional particle size analysis

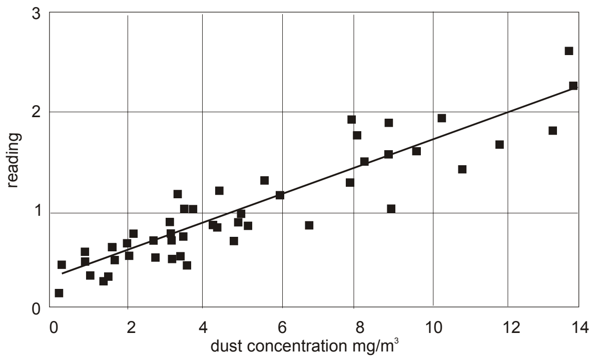


Figure 5:
Calibration curve of a Tyndallometer used in a Louisiana-type broiler house

Using total PM samples for additional particle size analysis may lead to failures in calculating the different fractions, if filters must be solved as necessary for the Coulter Counter. Agglomerates which are suspended in the air will be destroyed and a higher content of fine particles will be pretended. This effect is more severe measuring PM in livestock houses with high air humidity than measuring e.g. during combine harvesting or drying and cleaning cereals.

At the present time methods with aerodynamic separation are preferred.

Results

Cereal Production

During cereal unloading, cleaning and drying, dust is set free and emitted to the environment. 400 mg/m³ may be measured in the neighbourhood of the source during the short time of unloading. Because of the relatively coarse particles, the initial value of concentration decreases to 2 % at a distance of about 15 m.

For a drier with a capacity of 2-2,5 t/h, cereal exhaust concentrations between 1 mg/m³ and 100 mg/m³ with resulting mass flows (emissions) of 0,01 kg/h up to more than 0,6 kg/h have been measured. For a cereal cleaner with 20 t/h resp. 60 t/h the corresponding values are 17 mg/m³, 750 mg/m³ and 0,1 kg/h up to 5 kg/h. In the latter case dust separation is required. Particle size distribution of the emissions during drying shows mainly a higher content of fine particles than during cleaning. Up to 50% at drying but only 15% at cleaning had been measured /10/.

Both in drying and cleaning, the level of dust emission is strongly influenced by the kind of crop. Dust production from barley is more significant than from wheat.

Among mobile sources in plant production, combine-harvesters produce high dust emissions which also depend on the kind of crop, the soil, the climate and other parameters. Dust emissions are roughly proportional to the cut width /11/. In a particular case a width of 2 m resulted in emissions at a rate of 20 kg/h, while 4 m cut width resulted in 40 kg/h. Dust emissions at rates in excess of 60 kg/h have been measured. For creating emission inventories product related specific emission factors are required. For combine harvesting this factor is calculated in the range of 1.2-6.1 kg/t (TSP related to harvested cereal). Particle size distributions show aerodynamic 50 % diameters of about 15 µm and a potential of PM2.5 material mostly below 5 %.

Dusts in the neighbourhood of a combine harvester may cause allergic reactions. To protect the farmer against the airborne contaminants during mobile works in the fields a forced-ventilated, air-conditioned cab is the preferable way /12/.

Animal production

Dust from animal production inside livestock buildings is part of air quality and may affect the health and welfare of man and animal. Upon leaving the barn in ventilation flow or through other openings, dust becomes an environmental problem. Particles originate from the animal itself and from fodder and litter. They form a multi-component biological aerosol with a great variety of inorganic and organic material, because gases, bacteria and other germs are adsorbed and fixed on the surface of the dust particles. The strength of each source depends on parameters such as the species, stocking density, age of the animals, feeding and littering strategies, the climate conditions inside the barn and the behaviour of the animals. Environmental enrichments and e.g. lighting strategy influence the animals' activity and consequently dust emissions /13/. For international szenario, specific emission factors averaged for one year must be calculated. Therefore all time dependencies must be known on the scale of a day, the fattening periods and the season.

Dust emissions from cattle, pig and poultry houses in Northern Europe were measured and measurements of the air quality inside turkey houses were made, too.

Table 3 shows the results. The emission results are a part of a European Research Project /14/.

Table 3:
Mean emission rates of total dust on a 500 kg liveweight basis for different species

	Emission rates in mg/h (500 kg)		
	cattle	pig	poultry
Germany	184	651	2118
Denmark	128	1102	3509
Netherlands	143	674	3640
U. K.	97	633	3138

For the emission rates, the measured mass flow from a barn is related to the livestock unit (500 kg) basis, so that a direct comparison between the different species is possible. The lowest specific emission rates are found in cattle houses. The highest values are observed in poultry buildings especially for broilers on litter.

The values in the table are averages of measurements carried out at different times of the year in different barns in different countries. The aim of the European study was to provide the Commission with fundamental data regarding emissions in Northern Europe caused by animal production. Particle sizing of the emissions was not requested at that time.

For the farmer, more detailed information about the dust concentration in the course of a day may be more interesting, e. g. as a factor in animal health, welfare and productivity. Figure 5 shows the course of the total dust concentration in an experimental turkey house with a stock of 540 birds. Day and night time are to be distinguished significantly with higher value during the day. An averaged ratio can be calculated to ~ 2. Day and night time can be influenced by the farmer by switching light on/off which is clearly detectable in the dust concentration, see figure 6.

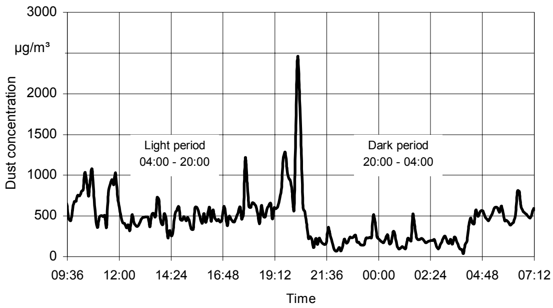


Figure 6:
Influence of lightening on dust concentration in a turkey barn

Measurements in another commercial freely ventilated and illuminated turkey production facility with a stock of 3000 birds show a proportion of 5 % PM 2.5 which means an average of 0.2 mg/m³ over a duration of 3h on day time.

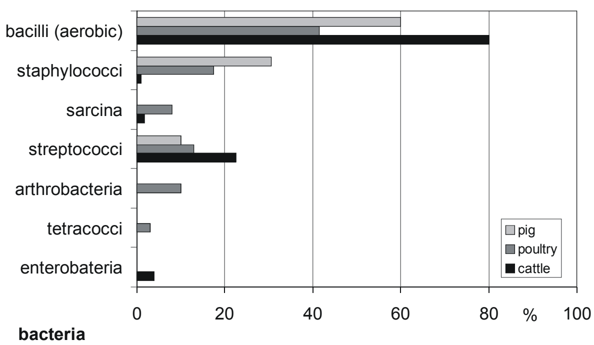
The content of PM10 or PM2.5 depends on factors of production and the species itself. A previous study of the air quality and the emissions from a large piggery with wet feeding showed PM2.5 ranging between 40 and 70 %. For particle size analysis Coulter Counter Technique was used which may lead to a higher content of small particles than aerodynamic measures, as mentioned above. These values must be seen with the total emission flow and the specific emission factor which is calculated to be approximately 12g/(h animal). The exhaust concentration of PM2.5 concerned is in the order of 0.5-0.9 mg/m³ with flow rates of 4.8 – 8.4 g/(h animal) /15/.

As mentioned above PM emissions in and from agriculture - especially in animal production - have a high content of organic material inclusive germs. In normal air germs are found in concentrations of 10^3 to 10^4 per m³. In animal production germ concentration - bacteria and fungi - is 2 decimal powers higher than in normal air /16/. In figure 7 the most important fungi and bacteria of animal production are given. The lengths of the columns are a measure for their frequency. The most common species of fungi are scopulariopses and of the bacteria the various bacilli. It is conspicuous that staphylococci and streptococci are found. It must be mentioned that there is a wide spectrum of fungi in poultry production in contrast to the low variety in pig houses. This observation is valid for the bacteriological examinations, too.

Conclusion

PM concentration, PM emissions and emission factors must be related to the different definitions of size

- looking to human (animal) health and welfare
- looking to transportation and effects in the ambient air
- the complex composition of the aerosols in agricultural production requires sensitive use of given size selective measuring procedures and special attention to the content of microorganisms of parts of it – bioaerosols.



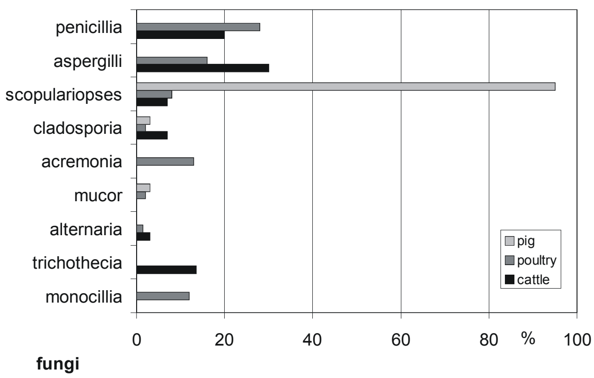


Figure 7:
Germ spectrum of total dust samples of animal production

Summary

Agriculture and the environment are connected interactively which means they emit and receive contaminants from each other, e.g. PM.

Emissions of agricultural PM result from animal houses, and the mobile and stationary equipment used in plant production. In comparison with other sources special time functions are to consider according to biological dependencies.

In most cases, PM emissions in and from agriculture affect man and animals in the living and working area mainly in so far as they affect air quality inside livestock enterprises. The portion of small particles for long range transport (PM2.5) has been found to be in the range of 5% up to 70% from total dust also depending on the measuring procedure. To confirm this result, more particle size sensitive measurements will be done.

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