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Synthesis of the Attenuation of Odour Intensity with Distance of Cattle and Pig Husbandry as well as Animal Husbandry combined with Biogas Facilities

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To date, recommendations for distances between animal husbandry and residential zones have been based either on empirical assumptions, on studies of individual animal species, or on dispersion modelling with assumptions concerning source strength and odour dispersion. However, a cross-species approach with corresponding field investigations had been missing. The aim of this cross-species synthesis was to determine the attenuation of odour intensity with distance, to give insights into the variability between different types of farm odour sources with regard to their odour impact in the field.
The synthesis is based on datasets of farms with cattle and pig husbandry, as well as animal husbandry combined with biogas facilities. In the case of cattle, loose dairy housing systems with and without an outdoor exercise yard were compared. Pig farms with forced or natural ventilation, with multiple-area pens and outdoor exercise yards were also part of the study. The farms with cattle husbandry and biogas facilities, two of which additionally kept pigs resp. poultry, covered a wide range and variety of emitting surface areas. During down-wind plume inspections in the field, assessors recorded their odour perception and odour intensity. The mean odour intensity in the down-wind plume was explained with a linear mixed-effects model. The fixed effects distance, emitting area, wind speed, and the type of farm odour sources (animal species, type of housing and facility) were significant. The highest odour intensity resulted from the animal housing with cattle and pigs combined with a biogas facility, followed by biogas facilities with cattle, with cattle and broiler chickens and from pig housing with forced ventilation, without outdoor exercise yard. The investigated cattle farms were characterised by lower odour intensity; but the effect of the outdoor exercise yard was obviously. Farms with a larger number of animals, with spatially extended area sources, e.g. with outdoor exercise areas, in the case of pigs also with natural ventilation and multi-area surfaces resulted in a greater spatial plume extent. Differences of animal species became clear, in that pig husbandry was characterized by a higher odour intensity than the attenuation curves of cattle husbandry.
The identified relationship of odour-relevant sources, wind speed and odour perception in the plume will create a better understanding of factors, which impact odour in the field. The observed decrease of odour intensity with distance, the ranking of animal species, housing systems and source characteristics can serve as a basis to improve minimum separation distance and the siting of animal husbandry near residential areas.

1. Introduction

To protect local residents from odour nuisance caused by animal husbandry systems, minimum distances MD are necessary to improve planning- and investment security for farms. Odour regulations are either based on air quality standards and limits, exposure assessment, no-annoyance or on best practice (Sironi et al., 2013). According to Eckhof et al. (2012), Nicolas et al. (2008) and Piringer and Schauberger (2013), the principle of assessing a minimum separation distance is based on an equation with a number of factors that depend on the type of animal, the size and characteristics of the operation and possibly topography, landscape or meteorology. To date, recommendations for distances between animal husbandry and residential zones have been based either on empirical assumptions, on field studies of individual animal species, or on dispersion modelling with assumptions concerning source strength and odour dispersion. Schiffman et al. (2001) listed

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reasons why accurate dispersion modelling has not yet been developed: agricultural facilities with a variety of odour sources, lack of surrogate components, additive and synergistic effects of components as well as deficits at close range. Hence, a systematic detailed validation of odour impact is missing. This applies also to a cross-species approach with corresponding field investigations. Schiffman et al. (2001), Yu et al. (2011) and Hayes et al. (2014) emphasized the importance of combined approaches with field testing. They also pointed out the relevance of odour intensity for odour impact.

In Switzerland, livestock farming has changed considerably. Whereas closed housing with forced ventilating predominated pig housing in the past, nowadays, many pig housing facilities are designed as multi-surface systems with exercise yards. Cattle farming changed from tie stall barns to loose housing, often supplemented by outdoor exercise yards. In combination with animal husbandry, agricultural biogas facilities came along. This means additional area sources from the storage of substrates and fermentation residues as well as biogas discharge may be relevant for odour volatilization, dispersion and impact. In Switzerland, especially changed housing systems, the variety of facilities involved and larger animal populations all called for an update of the technical principles published in the FAT Report No. 476 (Richner and Schmidlin, 1995) as well as the Draft Consultation Document of 2005 (SAEFL and Agroscope FAT, 2005). The aim of this cross-species approach was a synthesis of several studies with field plume inspections to determine the attenuation of odour intensity with distance, to give insights into the variability between different types of farm odour sources with regard to their odour impact in the field.

2. Studies and methods of field plume inspections with underlying datasets

The synthesis is based on datasets with down-wind field plume inspections of farms with cattle and pig husbandry, as well as animal husbandry combined with biogas facilities (Table 1). These comprised a cattle test area soiled with manure CT and farms with loose dairy cattle housing systems referred to as C+/C– with/without an adjacent outdoor exercise yard (Keck and Frei, 2016). With regard to pigs, forced and natural ventilation PF/PN with and without +/– outdoor exercise yards were investigated (Keck et al., 2004). In the study of animal husbandry combined with biogas facilities all eight farms kept cattle BC, one of them also pigs BCP and one broiler chickens BCR (Keck et al., 2014). The emitting areas included the animal husbandry, the storage of silage, farmyard manure and substrates. Their size varied between farms and according to the typical situation of animal husbandry in Switzerland. The emitting area of the cattle farms ranged between 100−600 m^2 and of the pig farms between 160−1,145 m^2. The combined farms with biogas facilities added up to 410−1,810 m^2, with a maximum surface area of the combined poultry and pig farms. Further details are depicted in the above mentioned publications.

Table 1: Description of the different types of farm odour sources with information on animal husbandry, exercise yards (ex.) and biogas facilities (with outdoor exercise yard +, without -)

Studies and abbreviations	Cattle yard test area CT	Cattle farms C	Pig farms P	Biogas Facility and Animal Husbandry BC
Farms [n] and number of animals (min.–max.) [n]	1 –	10 14–40 dairy cows	30 7-132 livestock units of which	8, of which 6 farms cattle (28–132) BC, 1 farm cattle and 200 fattening pigs BCP, 1 farm cattle and 12,800 broiler chickens BCR
Housing systems, exercise yards and biogas facilities	fresh soiled, cattle manure on solid flooring, free flow over uniform surface	loose housing: with C+ without C– adjacent outdoor exercise yard	forced ventilation: 8 farms without PF– 6 with ex. yard PF+ natural ventilation: 5 single-area pens without PN– 11 with ex. yard PN+	storage for substrates, manure and fermentation residues, fermenter, partly secondary fermenter
Size of emitting surface [m^2]	100	100–600	160–1145	410–1810

During the down-wind plume inspections in the field, trained assessors were positioned at various distances to the farm, mostly adjusted according to wind and source strength, with an exception in the pig study with three fixed distances (Table 2). In the down-wind plume, odour perception was recorded as well as odour intensity in ten-second intervals by means of inspection rounds, lasting ten minutes each. Odour perception was rated from 0 (imperceptible) to 6 (extremely strong). In addition, the type of identified odour was documented per round. Furthermore, a variety of different descriptive parameters was collected to describe the emitting sources and the local dispersion situation.

Table 2: Description of the methods of the down-wind odour plume inspections in the different studies and information on the extent of the studies (with outdoor exercise yard +, without -)

Studies and abbreviations	Cattle yard test area CT	Cattle farms C+, C–	Pig farms PF–, PF+, PN–, PN+	Biogas Facility and Animal Husbandry BC, BCP, BCR
Odour parameter	frequency, intensity	frequency, intensity	frequency, intensity, kind of odour	frequency, intensity, kind of odour
Assessors per inspection round [n]	5	5	3	6
No. of 10 min intervals with assessors [n]	40	114	639	785
Position in plume axis	transectional	transectional	longitudinal	longitudinal
Descriptive parameters	odour source characteristics (size of emitting areas, odour concentration), meteorological parameters (air temperature, wind velocity, wind direction)			

The data of these three studies were combined. The data evaluation was based on the inspection rounds with ten-minute average values of the odour intensity of the individual assessor and of the meteorological parameters wind speed and air temperature, the emitting area on the survey day and the respective distance to the farm. After a graphical analysis, the influence of fixed and random effects on the mean odour intensity was tested with a linear mixed-effects model (lme) in R 3.4.1, Version RStudio 1.0.143 on the level of date and ten-minute inspection rounds. In order to achieve a normal distribution of the data, the odour intensity was transformed with the square root.

3. Attenuation of odour intensity with distance

Figure 1 shows the individual mean odour intensity per assessor, grouped by the studies with cattle test yard, cattle, pigs and animal husbandry with biogas facilities. The cattle test area CT showed a higher level of odour intensity, even if the area was only 100 m^2. The dairy farms C+ and C– were characterized by smaller stock size (14-44 cows) and concomitant with this the size of the emitting sources and the distance of odour perception was of a smaller reach than the plots of pigs (P) and animal husbandry with biogas facilities (BC, BCP, BCR). It became obvious, that odour from animal husbandry with pigs as well as pigs and broiler chickens combined with biogas facilities resulted in a greater extent. The pig systems with PN– were characterised by a smaller stock size, whereas the farms with PF– had larger numbers of pigs. The farms with biogas facilities covered a wide range and variety of emitting surface areas.

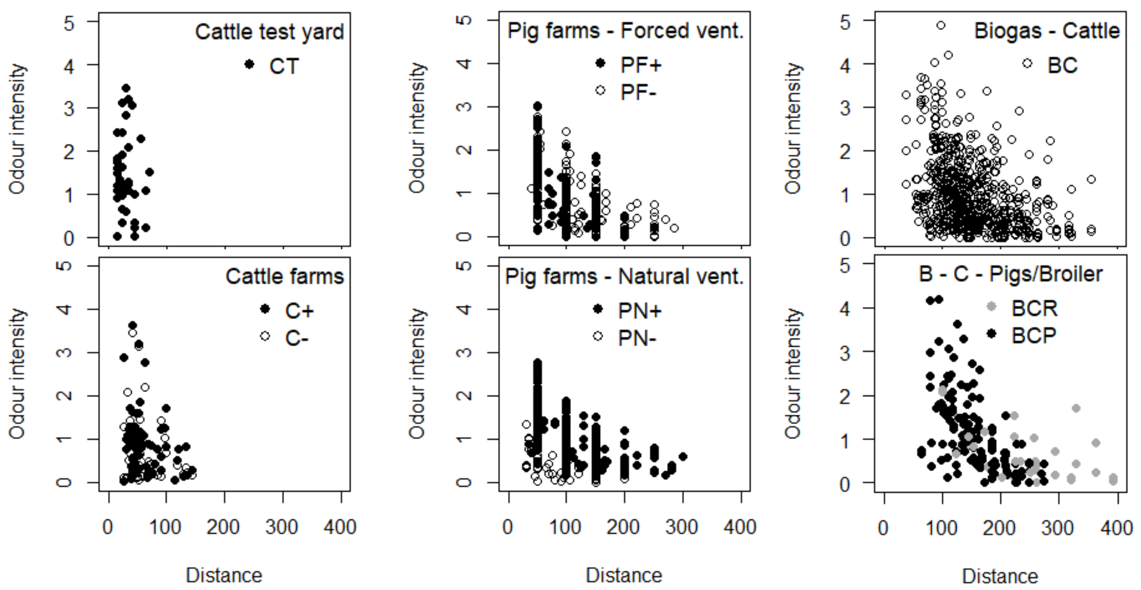

Figure 1: Mean odour intensities per assessor and inspection round depending on distance in the studies with cattle, pigs and animal husbandry combined with biogas facilities (with outdoor exercise yard ●/+, without o/-).

The mean odour intensity in the down-wind plume was explained with the linear mixed-effects model. The fixed effects distance, emitting area, wind speed, and the type of farm odour sources (animal species, type of housing and facility) were significant. An increase of the emitting area and wind speed resulted in a significant higher odour intensity. With increasing distance to the source, the odour is diluted. In a distance between 100 m and 200 m an increase of the distance by 50 m led approximately to a halving of the odour intensity. The effect of the different types of farm odour sources is described in the following chapter.

Table 3: Linear mixed-effects model to explain the square root of odour intensity based on field odour-plume inspections with the estimated fixed effects and the predicted random effects

Model	Parameter	F value	p value
Fixed effects	Intercept	$F_{1,\ 1069}$ = 1,801.5	<0.0001
	Distance	$F_{1,\ 1069}$ = 1,027.8	<0.0001
	Square of distance	$F_{1,\ 1069}$ = 7.7	0.0056
	Emitting area	$F_{1,\ 422}$ = 98.9	0.0001
	Wind speed	$F_{1,\ 422}$ = 17.2	0.0001
	Distance : wind speed	$F_{1,\ 1,069}$ = 13.3	0.0003
	Animal species, type of facilities and housing	$F_{1,\ 422}$ = 5.4	0.0001
Random effects	Survey day, round		

4. New studies and their integration into technical principles for minimum distances

The previously applied MD of the pig farms with forced ventilation PF– served as a reference (Richner and Schmidlin, 1995; SAEFL and Agroscope, 2005) in order to integrate the results of these studies of changed housing systems in the MD between animal husbandry and residential zones (Steiner and Keck, 2018). The MD for pig farms remained the same, e.g. 500 fattenings pigs with PF– required a minimum distance MD of 158 m. Starting from this fixed MD, the odour source strength OS was calculated backward according to Eq(1), applying the new odour attenuation curve and calculating the OS. The animal and system specific factor f_{system} was determined by inserting the emitting area EA in Eq(2). In addition, the calculation of the MD for the changed systems was shown in Eq(3) with an example of the animal area.

$$Odour\ source\ strength\ OS\ =\ 0.2\ e^{\left(\frac{\text{Minimum distance MD}}{72.1}\right)} - 0.2; \quad \text{Example}\ \ 1.6 = 0.2\ e^{\left(\frac{158}{72.1}\right)} - 0.2 \tag{1}$$

$$Factor\ f_{System}\ =\ \frac{\left(\frac{Odour\ source\ strength\ OS}{0.016}\right)^{1.35}}{Emitting\ area\ EA} \tag{2}$$

$$Minimum\ distance\ MD = -72.1\ \ln\left(\frac{0.2}{0.2\ + OS}\right) = -72.1\ \ln\left(\frac{0.2}{0.2\ +\ \sqrt[1.35]{EA\ \cdot f_{System}}\ \cdot 0.016}\right) \tag{3}$$

In Figure 2a) the predicted attenuation curve is depicted for the reference pig housing system PF– with forced ventilation and roof venting without an exercise yard and an emitting surface area of 400 m^2, 800 m^2 and 1200 m^2 (wind speed 1.5 m s^{-1}). The effect of emitting area becomes apparent. In Figure 2b) the attenuation curves of the different pig housing systems were modelled in an example with 800 fattening pigs, taking into account the differences of area per pig (systems without outdoor exercise yard 1 m^2 versus systems with outdoor exercise yard 1.65 m^2) and the differences between the four systems. The attenuation curves demonstrate the ranking of the four systems according to their odour intensity, starting from a lower level to a higher: PN– < PF– < PF+ < PN+. In addition to Keck et al. (2004) the system with single-area pens with bedding and natural ventilation without outdoor exercise yard PN– resulted in lower, whereas the systems with outdoor exercise yards and/or natural ventilation resulted in higher odour intensity levels.

For comparison with the different pig housing systems, the other species and types of farm odour sources were also predicted for a situation with a wind speed of 1.5 m s^{-1}. The emitting surface area was predicted for 400 m^2 (Fig. 3a) and 1200 m^2 (Fig. 3b). The highest odour intensity resulted from animal housing with cattle and pigs combined with a biogas facility BCP. Then followed biogas facilities with cattle BC, with cattle and broiler chickens BCR and farms pigs with forced ventilation, without outdoor exercise yard PF–. The investigated cattle farms C– were characterized by lower odour intensity; but the effect of the outdoor exercise yard C+ was obviously. The cattle yard test area CT was on the same level like the C+.

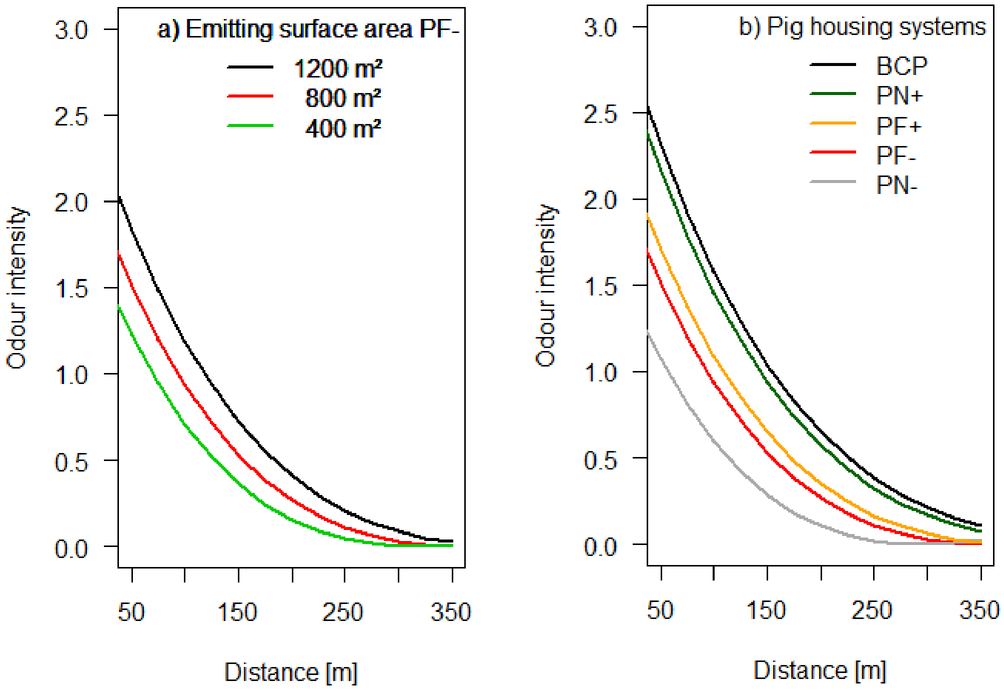

Figure 2: Predicted attenuation curves of odour intensity: a) reference pig housing system PF– with forced ventilation, roof venting without an exercise yard and varied emitting surface areas, wind speed of 1.5 m s^{-1}; b) effect of different pig housing systems, 800 fattening pigs (PF– and PN– 800 m²; PF+ and PN+ 1320 m^2).

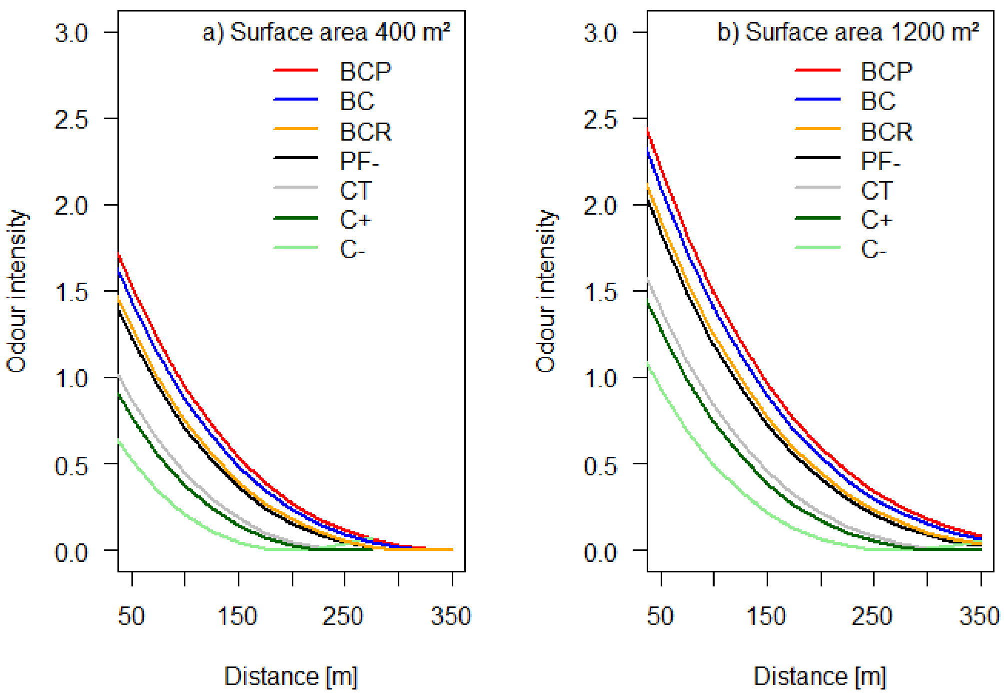

Figure 3: Predicted attenuation curves of odour intensity for the different types of farm odour sources with an emitting surface area of a) 400 m^2 and b) 1200 m^2 at a wind speed of 1.5 m s^{-1}.

5. Conclusions and outlook

On the basis of the ranking as established in this paper, the attenuation of odour with distance of different types of farm odour sources could be derived. Farms with a larger number of animals and/or with spatially extended area sources, e.g. with outdoor exercise yards, resulted in a greater plume extent. In the case of pigs, the odour intensity was higher with natural ventilation and multi-area systems. In general, pig husbandry was characterised by a higher odour intensity than the attenuation curves of the investigated cattle husbandry. The combination of biogas facilities with cattle, pigs or broiler chickens accounted for the highest odour intensity in the plume.

This synthesis made it possible to bring together individual studies of the team of authors, which were designed and analysed in the same way. The identified relationship of odour-relevant sources, wind speed and odour perception in the plume will create a better understanding of factors, which impact odour. In accordance with the downwind field odour studies of Zhu and Li (2000) from pig facilities, it was shown that the attenuation of odour with the distance is not linear. The observed decrease of odour intensity with distance, the ranking of animal species, housing systems and source characteristics can serve as a basis to enhance the siting of animal husbandry near residential areas. In situations with such spatially extended odour sources, the respective individual building arrangement and the spatial configuration is relevant for odour dispersion. Additional research about the site-specific influence of the local topography should be considered carefully to improve knowledge about relevant odour sources and dispersion, in order to improve planning processes and to avoid odour complaints.

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