Animal 16 (2022) 100435

Contents lists available at ScienceDirect

Animal

The international journal of animal biosciences

Review: Concrete outdoor runs for organic growing-finishing pigs – a legislative, ethological and environmental perspective

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A R T I C L E I N F O

Article history:
Received 29 October 2021
Revised 29 November 2021
Accepted 30 November 2021
Available online 5 January 2022

Keywords:
Ammonia emission
Animal welfare
Behaviour
Outside area
Pen design

A B S T R A C T

Concrete Outdoor Runs (**OUTRUN**s) are a characteristic part of organic pig housing. They must allow species-specific behaviours such as rooting and elimination, as explicitly required by organic legislation of the European Union (**EU**). However, OUTRUN design often fails to fulfil behavioural needs, and excreta can cover large parts of the OUTRUN leading to poor pen hygiene and associated ammonia (**NH_3**) emissions. This review integrates legislative, ethological and environmental requirements for OUTRUNs for organic growing-finishing pigs. While EU regulations specify some welfare-related standards for OUTRUNs (e.g. minimal space allowance), national and private standards interpret some aspects differently, e.g. the proportion of roofed and slatted floor area. Furthermore, reducing NH_3 emissions is equally a challenge for organic systems, even though EU legislation does not explicitly refer to OUTRUNs. Depending on the actual use of the OUTRUN for elimination, higher space allowance compared to conventional production norms increases the potential for a large NH_3-emitting surface. The design of pen features (e.g. roof, floor, enrichment) can encourage pigs to separate functional areas and consequently reduce the elimination area and associated NH_3 emissions. While providing the main lying area indoors, resting outdoors should be possible for sub-groups during the day. A roof protects pigs and resources (e.g. bedding) from adverse weather, but the effect on pig welfare and NH_3 emissions is site-specific. A floor design that ensures practicable manure removal and drainage is most important to reduce emissions. Providing opportunities for exploring and rooting in the OUTRUN has particular relevance for pigs' behavioural needs and can improve pen hygiene by reducing the elimination area. Cooling facilities are increasingly important to prevent heat stress and its detrimental effects on welfare and pen hygiene. Finally, practicability for farmers needs to be ensured for all resources provided in OUTRUNs, as good management is crucial. Research gaps emerge regarding the association between soiling and NH_3 and the influence of certain pen features (shape, roof, feeder location, pen partitions and wet areas) on pig behaviour and soiling.

Implications

Outdoor access for organic growing-finishing pigs is a public concern as consumers expect a high level of animal welfare and low environmental impact in organic pig production. This is reflected in organic legislation and private standards. However, nitrogen losses from European agriculture still remain on unsustainable levels in terms of air, land and water pollution. By integrating organic legislation, animal welfare and environmental requirements, we demonstrate potential for improving concrete outdoor runs for organic growing-finishing pigs and identify research gaps.

Introduction

The concept of naturalness plays a special role as a prerequisite for animal welfare and sustainable production in the organic movement for both consumers and producers (Lund, 2006). Providing livestock with opportunities to experience a more natural environment aligns with the ethical principles of Health, Ecology,

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https://doi.org/10.1016/j.animal.2021.100435
1751-7311/

Fairness and Care, which frame organic agriculture (International Federation of Organic Agriculture Movements (IFOAM), 2020). Furthermore, sustainable management practices such as organic farming are key when addressing environmental challenges (European Environment Agency (EEA), 2021), given that agriculture is the main source of nitrogen pollution to waters and accounts for 10% of all greenhouse gas emissions in the European Union (**EU**) (Oenema et al., 2007; EEA, 2021). Consequently, risk factors and mitigation measures concerning environmental impact and improvement of animal welfare need to be identified for such systems.

According to the Regulation (EU) 2018/848 (European Parliament and Council, 2018), all pigs should have permanent access to an "open-air area", which includes different forms of outdoor access such as pasture, paddocks with (bare) soil and Concrete Outdoor Runs (**OUTRUNs**). However, different standards (Table 1) and practices exist across Europe. Früh et al. (2014) found that some European countries provide pasture for all organic pigs all year round (United Kingdom), in summer (Sweden) or only during lactation and/or pregnancy (Denmark, France, Netherlands), while keeping growing-finishing pigs mainly in indoor pens with OUTRUNs. The latter predominates for all age categories in central Europe (Germany, Austria, Switzerland). Since indoor housing with OUTRUNs is prevailing for growing-finishing pigs in most European countries (Früh et al., 2014), this paper focuses on the design of OUTRUNs, which we define as the outdoor part of a housing system which (1) is permanently accessible from the indoor area (building or shelter, which is closed on four sides), (2) has a concrete floor (solid or partially slatted), and (3) may be partially roofed.

Compared to pasture systems, indoor systems with OUTRUN provide potential advantages regarding the performance of growing-finishing pigs (Leeb et al., 2019), protection against adverse weather and infectious diseases (e.g. African Swine Fever). However, many OUTRUNs do not fulfil behavioural needs, which may be contributing to a higher prevalence of tail lesions compared to pigs on pasture (Leeb et al., 2019). Offering organic pigs an OUTRUN also includes an additional step in the manure handling chain between pig house and manure storage, which needs to be addressed regarding environmental impact. The main risk factor is nitrogen loss as ammonia (NH_3) emissions from manure on the OUTRUN, while emissions of nitrous oxide (N_2O) and methane (CH_4) are negligible (Webb et al., 2001). In Europe, NH_3 emissions originate mainly from manure management, which must be optimised to fulfil environmental goals (Oenema et al., 2007; National Emissions Ceilings (**NEC**) Directive (EU) 2016/2284 of the European Parliament and Council, 2016). Large OUTRUN areas soiled with excrement can potentially result in more NH_3 compared to conventional indoor systems with lower space allowance (Dourmad et al., 2009; Olsson et al., 2014; Vermeer et al., 2015). Reducing NH_3 emissions in the OUTRUN contributes to reduce nutrient losses and greenhouse gases in subsequent steps of the manure management (Oenema et al., 2007; Petersen et al., 2013; EEA, 2021). As pigs prefer to separate lying and elimination areas, excretions accumulate in defined locations (Andersen et al., 2020). Appropriate pen design and management, which support the pigs' natural behaviour, may increase pen hygiene and reduce the NH_3-emitting surface (Philippe et al., 2011; Nannoni et al., 2020).

Based on scientific and practical knowledge regarding characteristics of OUTRUNs and their implications for pig behaviour and protection of the environment, the objectives of this paper are to (1) propose design features for OUTRUNs, and (2) identify knowledge gaps and paths for future research and development activities. To achieve these goals, a summary of European and national organic legislation and private standards will contribute to a common understanding of OUTRUNs for organic pigs. Subsequently, animals' behavioural needs and environmental requirements will be summarised, followed by a discussion of their trade-offs, synergies and feasibility.

Material and methods

Specific questions regarding the design of OUTRUNs have been rarely subjected to scientific research. Access to OUTRUNs is mostly part of the whole "package" of "improved husbandry systems". Given the unspecific nature of research on OUTRUNs and the variety of contexts in which they have been discussed, we did not aim for a systematic review. Rather, we reviewed legal requirements regarding OUTRUNs for selected European countries that represent the upper 25% of total organic pig population, namely Austria, Denmark, France, Germany, Italy, Netherlands, Sweden, Switzerland and the United Kingdom (Eurostat, 2021). We included EU organic legislation, national regulations and private standards of important organic label programmes (e.g., Soil Association, The KRAV Association, Table 1) going beyond EU requirements. We focused on those standards that directly or indirectly affect the design and management of OUTRUNs. Scientific studies on OUTRUNs were searched using predefined key words and complemented with literature on specific pen features, general aspects of pig behaviour and NH_3 emissions, also considering studies on conventional and free-range production (for a detailed description of the literature search, see Supplementary Material S1).

Legal framework

Permanent access to an "open-air area" is required for all livestock, including pigs (Regulation (EU) 2018/848, European Parliament and Council, 2018). It should allow species-specific behaviour and enhance animal health by strengthening natural defence (Chapter II, Article 6). Housing is not mandatory, but animals must have access to shelters to protect them from adverse weather conditions (Annex II, Part II, 1.6.2.). While ruminants must have access to pasture for grazing (Annex II, Part II, 1.4.1.), for pigs, an OUTRUN with rooting facilities is sufficient to comply with organic standards (Annex II, Part II, 1.6.5.). These general preconditions are complemented by specific requirements, e.g. regarding space allowance, and further expanded by national and private standards as compiled in detail in Table 1.

Notwithstanding the needs of animals, organic principles refer particularly to the protection of the environment (IFOAM, 2020; European Parliament and Council, 2018). Requirements for organic pig production regarding environmental impact refer mostly to the use and management of pastures and consider specifically nutrient leaching (European Parliament and Council, 2018), while not explicitly addressing NH_3 or other emissions in OUTRUNs. However, European farmers are obliged to respect the EU Nitrate Directive (91/676/EEC) to reduce nitrogen pollutants, protect waters and use good farming practices (Council of the European Communities, 1991) at any stage of production. Additionally, the NEC Directive (2016/2284/EU) determines reduction goals for air pollutants including particulate matter and NH_3 (European Parliament and Council, 2016) with major implications for European conventional and organic livestock production.

Behavioural needs

To address the legal requirement that organic housing systems should meet the ethological needs of pigs (European Parliament and Council, 2018), well-founded scientific knowledge is crucial.

Table 1
Organic regulations of the European Union (EU), complemented with additional national regulations and private standards concerning concrete outdoor runs (OUTRUNs) for organic growing-finishing pigs in Austria (AT), Denmark (DK), France (FR), Germany (DE), Italy (IT), Netherlands (NL), Sweden (SE), Switzerland (CH) and the United Kingdom (UK). Footnotes indicate references provided in the Supplementary Table S2.

Subject	EU organic regulations	National regulations	Private standards
Outdoor access	Permanent access to open-air areas, preferably pasture, whenever weather and seasonal conditions and the state of the ground allow.[1] OUTRUNs shall be attractive for pigs and provide outdoor climate.[2]	CH: Access on a daily basis for several hours.[10] NL: Floor condition cannot be a reason to limit access to OUTRUNs.[11]	Bio Suisse (CH): Outdoor access must be permanent.[31] Soil Association (UK): Permanent access to pasture/vegetated range.[32] The KRAV Association (SE): Possibility for grazing during the appropriate part of the year (i.e. not always required for each individual, if lifespan shorter than a year).[33] Demeter-International: Free contact with natural surrounding (sun, rain, natural soil).[34]
Space requirements for OUTRUNs	Minimum surface/pig:[3] ≤50 kg = 0.6 m^2 ≤85 kg = 0.8 m^2 ≤110 kg = 1.0 m^2 >110 kg = 1.2 m^2 (equals 43% of minimum pen area)	CH: Minimum surface/pig:[12] 25–60 kg = 0.45 m^2 60–110 kg = 0.65 m^2 AT*: A smaller indoor area is possible for the benefit of a larger OUTRUN if the total surface requirements are met.[13]	Minimum total outdoor surface/pen: Industry agreement (DK): 10 m^2 (growing pigs), 20 m^2 (finishing pigs)[35] Bio Suisse (CH): 7 m^2 (25–60 kg), 10 m^2 (60–110 kg)[36] FederBio (IT): The OUTRUN must have the same surface as the minimum indoor area.[37]
Roof	Open-air areas may be partially covered.[4]	Maximum covered surface (% of minimum outdoor area): CH, DK: 50 %[14,15], NL, SE: 75 %[16,17], AT**: 50–90 %[18], DE: 50%-90%, varying between Federal States.[19]	Bio Suisse (CH): Minimum open (not covered) surface:[38] 0.23 m^2/pig (25–60 kg) 0.33 m^2/pig (60–110 kg) (equals 51% of minimum outdoor area).
Flooring	Housing shall have smooth and non-slippery floors.[5] At least half of the minimum surface of both the indoor area and the OUTRUN shall be solid floor.[6]	DE: Slatted floors are not permitted in the OUTRUN.[20]	FederBio (IT), Bio Cohérence (FR): Slatted floor is not permitted indoors and outdoors.[39,40]
Enrichment	The exercise area shall permit rooting. For this purpose, different substrates may be used.[7] Roughage, fresh or dried fodder, or silage shall be added to the daily ration.[8]	Possible substrates: AT: Loose organic material on the floor (e.g. straw, hay, leaves, sawdust, spelt husks) or roughage on the floor or in a rack, which after provision is not significantly soiled.[21] DK: Straw, soil, silage, green fodder, etc.[22] FR: Straw, earth or others. Silage may be used as rooting material, but its provision only in a trough is not sufficient.[23] SE: Straw, peat, bark, sand/earth or silage.[24]	Soil Association (UK): Possible substrates: Natural materials e.g. bean haulm, bracken or rushes, sawdust and wood shavings, sand and non-organic straw. You must not use peat.[41] Prüf Nach!/Zurück-zum-Ursprung (AT): At least two different types of rooting material must be provided on a regular basis.[42]
Provision of feed and water	No specifications regarding the OUTRUN		
Thermoregulation	Access to shelters and means allowing regulation of body temperature.[9]	DK: Access to means for temperature control in the OUTRUN.[25] CH: Access to cooling (earth heat exchanger, air cooling, floor cooling, fogging systems, showers or wallows) for pigs ≥ 25 kg when temperatures exceed 25 °C.[26] SE: During the warm season, pigs kept outdoors should have access to a wallow.[27]	Dyrenes Beskyttelse (DK): Access to a mud bath (wallow) or sprinkler for pigs > 20 kg when the average daily temperature exceeds 15 °C.[43] Soil Association (UK): Wallows and/or shade over the summer month.[44]
Pen partitions	No specifications.	NL: At least 4 m unobstructed view from the rear end of the OUTRUN. The lower 50 cm of the partition may be solid.[28] FR: Pen partitions of the OUTRUN limited to the height strictly necessary to restrain animals in the pen.[29] An area with three solid walls and fully covered cannot be considered OUTRUN.[30]	Industry agreement (DK): Ensured view from the OUTRUN. Front fence should be open from a height of 60 cm. Minimum 10 m between buildings.[45]

* The national regulation has expired on January 15, 2020 and is currently under revision.
** OUTRUNs of new buildings may be roofed to a maximum of 50 and 75% in regions with high precipitation, existing buildings to a maximum of 90% (until 2030).

Jensen and Toates (1993) identify a need as "*a state, which, if not attained, causes suffering to an animal as indexed by disturbed behaviour, an increased risk of pathological and/or physiological signs of impaired welfare*". The need to perform the behaviour is independent of the type of environment in which the animal lives (Jensen and Toates, 1993). A source of information about the needs of pigs may therefore be their natural behaviour. Like their ancestor the wild boar, domestic pigs distinguish functional areas for behaviours such as resting, exploration, elimination (defaecation and urination), thermoregulation and social behaviour (Stolba and Wood-Gush, 1989). Another important characteristic to consider is pigs' behavioural synchronisation (Rodríguez-Estévez et al., 2010; Zwicker et al., 2012), which will influence the size of functional areas required by a group.

Resting

Domestic pigs under semi-natural conditions choose sheltered lying areas, protecting them from wind and rain (Stolba and Wood-Gush, 1989). Pigs prefer to lie close to solid pen partitions, which provide protection from draughts (Jackson et al., 2020), on a soft surface with similar texture to soil (Beattie et al., 1998). During the night, animals rest together in a common area and behave as a united herd, while they rest outside the shelter in smaller subgroups during daytime (Stolba and Wood-Gush, 1989; Rodríguez-Estévez et al., 2010). Under organic conditions, pigs with access to an OUTRUN rest outdoors during daytime, even though they have access to an indoor area with straw bedding (Olsen et al., 2001). However, Argemí-Armengol et al. (2020) observed a slightly higher proportion of pigs resting in the indoor area than in the OUTRUN (73.2 vs 65.6%) during the day.

Exploring and rooting

Pigs explore their environment for both foraging and investigating their surroundings (Studnitz et al., 2007). In a semi-natural environment, pigs spent 50–90% of the daylight period on rooting and/or grazing and 5–25% on investigating and walking over the enclosure (Stolba and Wood-Gush, 1989). This indicates that pigs are generally exploratory animals with an appreciable proportion of their time devoted to moving around. The proportion of pigs present in the OUTRUN during the daytime varies across studies, ranging from 15% (Olsen et al., 2001), 30% in the early afternoon (Vermeer et al., 2015) to 39% (Knoll et al., 2021), with most pigs being active. The proportion correlates positively with sunshine and increasing outside temperatures over ranges of 4.4–23.7 °C (Olsen et al., 2001) and −3.5 to 29.7 °C (Knoll et al., 2021). Providing roughage in a rack (Høøk Presto et al., 2009) or a rooting area (Vermeer et al., 2015; Olsson et al., 2016b) in the OUTRUN can increase activity and attracts pigs to the OUTRUN. Conversely, providing oat silage indoors (compared to straw only) showed no effect on the time budget in the OUTRUN (feed and water outdoors) or indoor area, but it increased interactions with pen fixtures (Argemí-Armengol et al., 2020). Providing alfalfa in the indoor area reduced time spend on a bare outdoor area (Kozera et al., 2014). Olsen et al. (2002) reported that adding roughage (barley-pea whole crop silage) in the OUTRUN decreased the frequency of aggression, even though the pigs had access to straw in the indoor area. It is well known that providing pigs with environmental enrichment, as straw or roughage, decreases redirected exploratory behaviour towards pen-mates, aggression and tail biting but increases exploratory behaviour directed towards the substrates (Studnitz et al., 2007). The method of provision (e.g. on the floor or in a rack) may also influence the use, as mentioned by Van de Weerd and Day (2009). Pigs prefer to be active simultaneously, and thus accessibility of enrichment materials plays an important role (Zwicker et al., 2012). Especially in pens with large group sizes, allocation of the enrichment materials in different areas of the OUTRUN might be a way to reduce competition and increase the use of enrichment.

Feeding and drinking

Domestic pigs show most activities, including feeding and drinking, during the day (Villagrá et al., 2007; Guo et al., 2015). Pigs kept in a semi-natural environment (Stolba and Wood-Gush 1989; Rodríguez-Estévez et al., 2010) divide into smaller sub-groups of 5–6 animals for foraging during the day. Only a few studies have focused on the location of the feeder. Stolba and Wood-Gush (1989) reported that more than 89% of the communal nests were more than 30 m away from the feeding site (concentrated feed). Studies investigating the effect of drinker position indicate that pigs preferably use drinkers in the OUTRUN compared to indoors (Vermeer et al., 2015). Frequency of drinking is correlated with elimination (Guo et al., 2015). However, as there is a correlation between drinking, eating and activity (Villagrá et al., 2007), it cannot be concluded if elimination is related to drinking or general activity.

Elimination behaviour

Pigs eliminate away from their lying area, and this appears to be innate. The behaviour evolves with age, i.e. the distance between elimination and lying area gradually increases (Andersen et al., 2020). In accordance, most studies of systems where the lying and feeding areas are located indoors show that pigs prefer to eliminate in the OUTRUN (e.g. Olsen et al., 2001; Guo et al., 2015). With increasing age, the percentage of defecations (Olsen et al., 2001) and the proportion of nutrients (N, K, P) (Olsson et al., 2014) deposited in the OUTRUN increased. In studies of free-range pigs, no defecations were observed within a distance of about 1 m (Salomon et al., 2007) to 5 m (Stolba and Wood-Gush, 1989) from the lying area. These observations indicate that, although pigs do not eliminate within a certain distance from the resting area, the distance they are willing to move away from it for elimination is limited, depending on the age of the animals. More elimination has often been observed to occur at the far end of the OUTRUN compared to the area close to the indoor entrance, but the restriction of the elimination area to a small part of the OUTRUN was not pronounced if no resources were provided there (Vermeer et al., 2015; Olsson et al., 2016b). Adding enrichment to the OUTRUN, e.g. roughage (Olsen et al., 2001) or a rooting area (Vermeer et al., 2015; Olsson et al., 2016b), directed the elimination behaviour away from these areas and thereby reduced the space used for elimination in the OUTRUN. Vermeer et al. (2015) reported that adding an extra water supply in the OUTRUN decreased fouling near the outdoor drinker, but increased fouling in the indoor area. In contrast, for conventional pigs with access to OUTRUNs, Ocepek et al. (2018) reported that placing two drinkers in the OUTRUN, instead at the indoor slatted area, improved cleanliness indoors. By moving the drinkers from the indoor to the outdoor area, the number of pigs lying in the indoor slatted area increased, and the number of urinations and defecations on the indoor solid floor decreased, whereas the number of urinations in the OUTRUN increased. The least elimination behaviour per m^2 was observed in the indoor slatted area, irrespective of drinker position. However, stocking density may have affected the results, as the in- and outdoor area per pig was lower than EU organic regulations require in the study by Ocepek et al. (2018), but higher in the study by Vermeer et al. (2015). Olsen et al. (2001) argue that wet areas may attract elimination, as they found about 50% of urinations and defaecations occurring in the water-filled wallow in the OUTRUN. In contrast, no defecation was observed close to the water for sows (Watson et al., 2003) and growing pigs (Salomon et al., 2007) on pasture. Thus, there is no evidence indicating that pigs prefer to eliminate closer to the water resource, but the location of the water resource seems to influence the elimination pattern in the pen, maybe by influencing the general use of the pen. In the review by Andersen et al. (2020), they concluded that we still lack knowledge about the basic elements behind the pigs' choice of elimination area. It remains unclear whether the choice is simply due to deselection of certain areas (e.g. the lying and feeding areas) or whether there are particular features and characteristics, which motivate and affect the pigs' choice of elimination area (e.g. odour, visibility of conspecifics).

Thermoregulation and comfort behaviour

Heat is exchanged with the environment through radiation, convection, conduction and evaporation. The principal environmental factors affecting the animals' heat loss are air temperature, air velocity, temperature on radiation surface, temperature of the conductive area and humidity (Collier, 2012). Pigs can influence the sensible heat loss (radiation, convection and conduction) by behavioural adjustments. At low temperatures, pigs huddle, lie with maximised body contact and mainly on the belly, whereas at high temperatures, they are scattered and lie mainly on their side (e.g. Olsen et al., 2001). With increasing temperature, pigs change their preferred lying area from the straw-bedded area to the concrete floor, including the OUTRUN, and prefer shaded areas (Olsen et al., 2001). In accordance, wild pigs seek the cool moist forests during hot dry days, whereas during cold days, they choose their resting places on sun exposed slopes (Allwin et al., 2016). Blackshaw and Blackshaw (1994) reported that, regardless of age, the majority of pigs (60–70%) housed outdoors in pens sought shade at an air temperature between 20 and 25 °C and the number increased with increasing temperatures. In addition, their results indicate that older animals look for cooling facilities at lower temperatures than younger pigs.

Pigs cannot sweat and, as a more active behavioural reaction to high temperatures, they will start wallowing, i.e. moistening the skin with water or mud, which enables cooling by evaporative heat loss (Bracke, 2011). After wallowing, pigs like to rub their skin against tree trunks or edges to remove the dried mud. Covering the skin with mud may also protect them from sunburn (Bracke, 2011). In tropical conditions, pigs provided with water baths or water sprinklers had lower respiration rates and skin temperatures than a control group, and fewer pigs were lying laterally (Huynh et al., 2006). However, the evaporative heat loss is less effective when using clear water compared to mud, as it lasts for a shorter time and declines rapidly (Ingram, 1965). According to Huynh et al. (2006), adding an OUTRUN to the pen (i.e. increasing space allowance per pig) reduced the number of pigs lying laterally in pens with indoor water baths; in pens with sprinklers (indoors), it reduced the respiratory rate. In the same study, access to an OUTRUN increased rectal temperature in the afternoon regardless of treatments, which the authors attributed to the lack of shade but also to the solid walls around the OUTRUN affecting the pigs' heat loss.

Social behaviour and play

Pigs are social animals living in groups. Under natural conditions, a few sows live together with their offspring (10–30 animals) and larger groups split up into sub-groups (Stolba and Wood-Gush, 1989). Studies comparing different group sizes (e.g. Turner et al. (2000) comparing 20 vs 80 pigs) did not reveal differences in aggressive behaviour. Moreover, space allowance seems to be more important than group size with regard to agonistic behaviour, as reduced space allowance increases aggressive interactions and skin lesions (Turner et al., 2000). Pigs reared in an enriched environment with different functional areas, including possibilities to root, displayed less aggressive behaviour when confronted with unfamiliar animals compared to pigs reared in barren environments, indicating a direct positive effect of enrichment on aggressive behaviour (O'Connell and Beattie, 1999). This is supported by the results of Wei et al. (2019), comparing deep-litter systems to systems with additional outdoor space but no rooting substrate. Pigs in deep-litter systems showed fewer aversive social interactions including aggression and less abnormal behaviour. However, pigs with an OUTRUN showed more play behaviour, which may be due to higher total space allowance and a more differentiated space for playing (Wei et al., 2019).

Environmental requirements regarding ammonia emissions

The EU Nitrate Directive (Council of the European Communities, 1991) promotes good farming practices. This also applies to OUTRUNs that should be designed to prevent pollution of surrounding land and water with manure surface run-off. Webb et al. (2001) estimated that OUTRUNs account for 13% of the total NH_3 emissions from British livestock production, while N_2O and CH_4 emissions from OUTRUNs play only a minor role. In agreement, Dourmad et al. (2009) found that NH_3 accounts for 90% of total N emissions from the pig barn for systems with and without OUTRUN. Total NH_3 emissions tended to be higher in systems with OUTRUNs compared to conventional systems. Thus, we focus on NH_3 emissions from excretions as the main concern for OUTRUNs, although the role of other pollutants such as N_2O and CH_4 in organic production in general should be considered when assessing environmental impact from the whole husbandry system.

Generation of ammonia emissions

Ammonia emissions primarily result from a breakdown of urea in the urine, catalysed by the urease enzyme in faeces (Philippe et al., 2011). Higher NH_3 emission from organic production compared to conventional indoor production is mainly caused by a larger soiled and emitting surface due to the increased floor space allowance per pig (Olsson et al., 2014). Ivanova-Peneva et al. (2008) found a significant effect of poor pen hygiene (i.e. area of floor with soiling) in organic systems with mostly solid floor, leading to high NH_3 emissions. Accordingly, Nannoni et al. (2020) conclude that reducing the area used for elimination can help to reduce NH_3 emissions.

In organic housing systems with OUTRUNs, most of the excreta are deposited outdoors (e.g. Olsen et al., 2001; Guo et al., 2015; Vermeer et al., 2015), resulting in NH_3 emissions that originate mainly from outdoor concrete floors. Measurements of NH_3 emissions in indoor pig houses have shown that the duration that excreted urine is exposed to the environment has great significance: urine excreted onto a dirty floor where the enzyme urease is present results in maximum NH_3 emissions already in the first two hours (Philippe et al., 2011). Therefore, a fast removal of urine from the OUTRUN to a covered storage pit will efficiently reduce NH_3 emissions. NH_3 emissions also occur from excreted faeces, but only after decomposition of organic nitrogen, which takes a longer time. Kellems et al. (1979) showed that NH_3 emissions from faeces increased very slowly during a period of 25 days. Thus, a fast removal of faeces – in contrast to urine – is not that crucial to reduce NH_3 emissions but more important for achieving good hygienic conditions on the OUTRUN.

Factors influencing ammonia emission

While measuring NH_3 emission in an indoor situation is relatively simple by continuous sampling of the ventilated air, this is not the case for naturally ventilated open-air areas. On the OUTRUN, many factors such as temperature, airflow and precipitation influence NH_3 emissions and, together with the absence of a central ventilation point, complicate the measuring technique (e.g. Ivanova-Peneva et al., 2008; Olsson et al., 2016b). Philippe et al. (2011) extensively reviewed the factors influencing NH_3 emission from pig houses, such as floor type, manure removal system and climatic conditions. Temperature is one of the main influencing factors for the generation of NH_3; there is a direct positive correlation between temperature and generation of emissions (urease activity, dissociation and volatilisation of NH_3) (Philippe et al., 2011). In systems with OUTRUNs, seasonal effects on temperature in the OUTRUN and, to a lesser extent, in the indoor area are considerable (Dourmad et al., 2009), making NH_3 emissions difficult to control. Moreover, pigs' behavioural changes at high temperatures, i.e. lying patterns (Olsen et al., 2001) and wallowing (Bracke, 2011), indirectly favour NH_3 emissions through increasing the soiled and emitting surface (Ivanova-Peneva et al., 2008; Philippe et al., 2011). Airflow (wind and ventilation) considerably influences NH_3 emissions. Increasing air speed at the manure and urine surface contributes to higher emissions (Philippe et al., 2011). Additional water, e.g. in the form of rainwater or showers, has the potential to decrease NH_3 emission by diluting the NH_3 concentration in the liquid and therefore changing the chemical equilibrium between liquid and gaseous phases (Philippe et al., 2011). Jeppsson et al. (2021) found a reduction of NH_3 emissions by 45% in partly slatted indoor pens with showers during the hot season, probably due to a combined effect of reduced pen soiling and dilution of urine. However, this has not been tested in OUTRUNs.

Besides environmental influences, the floor type affects NH_3 emissions. While a direct comparison between slatted, solid concrete and bedded floors is difficult, supplying increased amounts of straw in straw-based systems seems beneficial. Few studies on NH_3 and N_2O emissions from bedded areas have been conducted in conventional pig production systems. The type and degree of emissions from bedding depend on chemical and physical environmental factors, which can either increase or decrease the emissions (Jeppsson et al., 1997). Several processes contribute to the decomposition of organic material and vary both over time and between different parts of the bedded area (Jeppsson et al., 1997). However, there is a lack of knowledge about emissions from bedded areas outdoors. Most probably, the risk of emissions is different due to exposure to seasonal effects in comparison with indoor bedding. Regarding slatted floor systems, the floor material is an important influencing factor. Commonly used concrete slats result in higher NH_3 emissions compared to metal or plastic slats, which seem to have better drainage properties (Philippe et al., 2011). Systems with partly slatted floors seem to have lower emissions as long as the solid area remains clean (Philippe et al., 2011).

NH_3 emissions in OUTRUNs are highly influenced by continuously changing site-specific conditions such as temperature, precipitation and pig activities, which can result in either higher or lower emissions. This makes it difficult to obtain representative measurements of NH_3 emissions from OUTRUNs. For a relevant comparison between outdoor and indoor pig production, the total NH_3 emissions from housing system, storage and spreading of the manure should also be considered.

Discussion

Since the OUTRUN is the most visible part of the pen, it can enhance the visibility and transparency of the benefits of organic pig production. However, the socially perceived benefit of an OUTRUN for the pigs depends on their appearance. Citizens rated the benefits of fully slatted OUTRUNs lowest compared to other improvement measures such as straw, plastic or wooden objects and showers (Schütz et al., 2020). Improvements regarding pig welfare and environmental impact are important societal issues. EU legislation provides a common framework for the general idea of outdoor access when setting minimum requirements. Since clear definitions of "open-air", "indoor" and "outdoor" areas are lacking, the regulation offers scope for different interpretations, e.g. regarding roofing or the design of the enclosure. National legislation and private standards specify additional requirements for OUTRUNs, e.g. maximum roofing or an unobstructed view (Table 1). While these mainly relate to issues of husbandry and animal welfare, they take little account of environmental issues specifically associated with OUTRUNS, such as NH_3 emissions. One reason for this is that effectively reducing NH_3 emissions requires a more integrated approach, considering all parts of manure management on the farm (Oenema et al., 2007). This is also reflected in the EU Nitrate Directive (Council of the European Communities, 1991) and the NEC Directive (European Parliament and Council, 2016), which stipulate NH_3 reduction in all steps of manure management – handling, storage and spreading – to reduce environmental impact.

Much can be learned from best-practice experiences and from applied research to improve attractiveness for pigs and reduce NH_3 emissions of OUTRUNs. Although a number of studies on behaviour and environmental impact exist for indoor housing (e.g. Van de Weerd and Day, 2009; Philippe et al., 2011) or pasture (e.g. Salomon et al., 2007; Rodríguez-Estévez et al., 2010), only a few studies specifically investigate OUTRUNs (e.g. Ivanova-Peneva et al., 2008; Olsson et al., 2016b) due to the small size of the organic sector, its complexity and variation in systems. In the following sections, we will discuss the influence of different pen features, trying to integrate current legislation, ethological needs and environmental requirements regarding NH_3 emissions. To illustrate the consequences for practical implementation of the described features, we provide an example for a layout of a pen with an OUTRUN (Fig. 1, Supplementary Table S3). However, the successful implementation also depends on the management by farmers and should therefore consider practicability, workload and production costs.

Size and shape

According to EU organic legislation, about 43% of the total surface area of the pen has to be outdoors and should serve as space for elimination and rooting (Table 1). In some countries, however, national and private standards favour a larger OUTRUN or require a minimum total surface area per pen (Table 1). Large groups offer more total space, better enabling space-consuming behaviours like fighting or locomotory play. Pigs may not only visit the OUTRUN for elimination and exploration but also for resting during the day (Olsen et al., 2001; Argemí-Armengol et al., 2020). Therefore, in addition to an indoor lying area, which is large enough to enable all pigs lying together, the OUTRUN should also offer some space away from other resources for resting during the day (Fig. 1).

Regarding NH_3 emissions, a larger soiled floor area results in higher NH_3 emissions in the OUTRUN (Olsson et al., 2014). Pen hygiene could be more difficult to maintain in large groups with more diffuse elimination patterns, i.e. more variation in walking distances from lying to elimination areas. However, the soiled surface per pig may be similar or even smaller than in small groups, as long as pigs do separate functional areas (Andersen et al., 2020). The design of the OUTRUN (width, length, location of resources), in addition to the size, seems to be most important to ensure the separation of functional areas regardless of group size. It will affect the elimination behaviour, as it may limit the distance the pig is able to move away from one or more resources. This can make the pigs prioritise between resources they want to move away from for elimination. Consequently, they will eliminate where space is available that is not "occupied" by other resources or activities. Watson et al. (2003) discuss that the pigs' preference to eliminate far away from their lying area could direct elimination towards "the far end" of an elongated paddock. Dutch practical experience (InfoMil Kenniscentrum, 2015) recommends a ratio between pen length and width of 2:1 to direct elimination towards the far end of the pen, away from lying and feeding (Fig. 1). In any case, pigs need sufficient space to be able to separate the functional

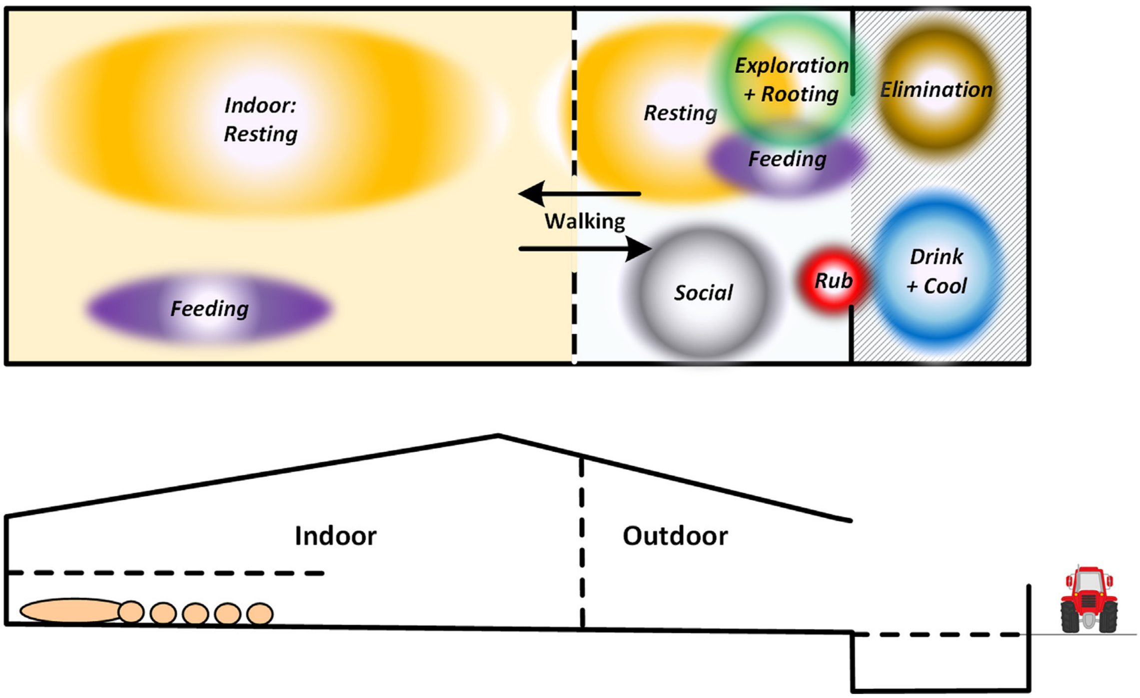

Fig. 1. Schematic layout and cross section of a pen with concrete outdoor run (OUTRUN) for growing-finishing pigs considering different functional areas. Indoor: Straw bedded lying area and feeding. OUTRUN (solid floor, roofed): Space for resting during the day, rooting and provision of roughage/feeding, free space for social interaction and locomotion, rubbing/brush close to cooling facility. OUTRUN (slatted floor, unroofed): Elimination area, "wet area" with drinkers and cooling facility.

areas from each other. Further research is needed on the space required for the different functional areas and the effect of the shape of OUTRUNs.

Roof

A roof protects pigs from rain, wind and sunlight and keeps bedding, rooting material and feed provided in the OUTRUN dry. However, EU legislation demands that animals can experience the outdoor climate, and a fully roofed OUTRUN is not allowed (European Parliament and Council, 2018). Interpretation of the necessary proportion of unroofed surface in the OUTRUN varies across countries (Table 1). It is commonly argued that having the choice between different climatic zones (e.g. roofed and unroofed) is beneficial for animal welfare and provides additional environmental stimuli. For wild pigs, the choice between shaded and unshaded areas is reported to be weather dependent (Allwin et al., 2016). Domestic pigs are descended from forest-dwelling wild boars, thus accustomed to shady areas (Stolba and Wood-Gush, 1989). Unlike wild pigs, domestic pigs have access to a warm dry indoor area. Being able to choose a sunny area during cooler periods is therefore not necessarily a behavioural need for domestic pigs as it is for wild pigs. Pigs housed in systems with OUTRUNs may suffer from sunburn, depending particularly on the degree of roofing. Cagienard et al. (2005) reported a mean percentage of 2.9% (ranging from 0 to 47%) of pigs with sunburn in a housing system with an OUTRUN. However, the authors did not indicate the degree of roofing of the OUTRUN. Providing sufficient shade has also been reported to increase play in systems with OUTRUNs (Olsen et al., 2002). Nonetheless, offering choices gives a greater sense of autonomy, which is in line with the principles of organic practice. However, scientific studies on how pigs perceive direct exposure to climatic conditions are lacking.

The degree of roofing influences NH_3 emissions as it affects rainwater in the slurry. The diluting effect of additional water can reduce NH_3 emissions (Philippe et al., 2011; Jeppsson et al., 2021). The situation is more complex when there is bedding material in the unroofed area, depending on absorbance capacity of the material. A high percentage of roofing provides more shade and may therefore reduce temperature, which has a mitigating effect on NH_3 emissions (Philippe et al., 2011). The extent and location of roofing could be used to direct pigs' behaviour, e.g. to ensure a dry and protected resting area in the OUTRUN and thereby reduce the area used for elimination (Fig. 1). The need for a partial roof depends on climatic conditions, in particular precipitation, building orientation (sun/wind) and provision of additional resources such as a rooting area, which need to be covered (Olsson et al., 2016a). To our knowledge, the influence of the degree of roofing on pig behaviour and NH_3 emissions has not been studied so far and needs further investigation.

Floor

The minimum solid area of 50% of the outdoor surface defined by the European Parliament and Council (2018) is important in terms of animal welfare as pigs use the OUTRUN for playing and agonistic interactions (O'Connell and Beattie, 1999; Wei et al., 2019). A dry and non-slippery solid floor is a prerequisite to allow locomotion and social behaviour without risking injuries. A solid concrete surface also facilitates the provision of bedding and enrichment material on the floor for exploration and rooting in the OUTRUN (Van de Weerd and Day, 2009). Although pigs prefer a surface similar to soil, e.g. peat, compost (Beattie et al., 1998), these materials are rare or not allowed in practice. Providing additional areas with a cooler surface in the OUTRUN, e.g. by reducing bedding material, is important at high temperatures when pigs increasingly lie on a cooler surface such as concrete (Olsen et al., 2001; Knoll et al., 2021).

Some drainage or slatted floor is beneficial for pen cleanliness and NH_3 reduction (Fig. 1). Philippe et al. (2011) conclude that a partly slatted floor is favourable in terms of both animal welfare and NH_3 emissions, as long as the solid part remains clean and dry. A slope of 2–4% of the solid floor can help to drain liquids through the slots of the slatted floor. The texture of slatted floors also affects NH_3 emissions, as smooth materials (cast iron, metal and plastic) result in less NH_3 than concrete (Philippe et al., 2011). However, low attractiveness of these materials for locomotion and higher risk of leg disorders need to be considered; this may be, next to cost, a reason to choose concrete slats in OUTRUNs. Moreover, in organic systems, fibrous manure and straw may accumulate on metal or plastic slats with a negative impact on functionality of the manure system. Therefore, bedding should be provided on a level solid floor or with a barrier to slow down the disappearance of material into the slurry pit. A general comparison between slatted, solid and bedded flooring is difficult, as many factors such as pen design, weather conditions and bedding type affect NH_3 emissions. It is more important that the floor is dry and clean and the soiled area as small as possible. An automatic scraper can clean the OUTRUN several times per day but with special attention for interactions between pigs and scraper. Yet, successful examples with this technology are scarce. Straw-based manure is commonly removed by tractor or manually. Overall, floor types which are easiest to keep clean under the individual farm conditions and allow locomotory behaviour without injuries are to be preferred.

Enrichment material

EU regulations emphasise the provision of rooting material in the OUTRUN (European Parliament and Council, 2018), while suitable materials are regulated on a national or private basis in some countries (Table 1). A structurally separated rooting area with substrates such as wood shavings, peat or compost is highly attractive for pigs, but adding feed pellets to the substrate does not seem to increase exploration (Olsson et al., 2016b; Knoll et al., 2021). Pens with rooting areas showed improved pen hygiene and reduced emissions in OUTRUNs (Olsson et al., 2016b; 2016a). However, practicability issues, e.g. the need for a roof (Olsson et al., 2016a), difficulty of mechanical cleaning and increased labour through frequent change of the substrate need to be considered. Providing roughage outdoors (Fig. 1) motivates pigs to visit the OUTRUN (Høøk Presto et al., 2009), while providing it indoors did not show positive effects on the usage and behaviour outdoors (Kozera et al., 2014; Argemí-Armengol et al., 2020). Provision of roughage on the floor corresponds to the pigs' natural feeding behaviour but can result in considerable wastage and impaired functionality of slatted floors, which may increase dirtiness and NH_3 emissions. Roughage in racks is also attractive for pigs (Høøk Presto et al., 2009), but sufficient access needs to be ensured to avoid agonistic behaviour and enhance exploration (Zwicker et al., 2012). For the farmer, good accessibility is important for frequent and easy provision and cleaning. Other enrichment objects such as hemp ropes or pieces of wood are mostly offered hanging, which provides opportunities for their use in slatted parts of the OUTRUN. However, they are not rootable or edible (Van de Weerd and Day, 2009) and should therefore only be complementary to other enrichment. Rubbing is part of pigs' comfort behaviour (Stolba and Wood-Gush,1989; Allwin et al., 2016), especially in the context of wallowing and thermoregulation (Olsen et al., 2001). Brushes or tree trunks to rub against, e.g. near cooling facilities (Fig. 1), could enhance attractiveness of the OUTRUN, but their effect on behaviour and welfare lack scientific evaluation. When positioning resources for exploration in the OUTRUN – thus focusing local activity – elimination behaviour can be directed to a specific area. This may help to decrease the soiled area and therefore reduce NH_3 emissions.

Feeders

As it is recommended that feeders should be located away from the resting area (Stolba and Wood-Gush, 1989), the OUTRUN could be a suitable location for feeding. To our knowledge, no study has compared the effect of feeding indoors or outdoors on pig behaviour and pen hygiene. Indoor feeders (Fig. 1) may be advantageous in terms of inspection and maintenance. Outdoor feeders could reduce the area used for elimination outdoors by avoidance of elimination close to the feeder (Andersen et al., 2020), but may increase elimination in the indoor area. On the other hand, pigs also avoid eliminating close to the resting area, which is often located indoors. Thus, the effect of feeding outdoors on pen hygiene may be related to the size of the indoor- and outdoor areas, respectively, as it affects the pigs' ability to find an elimination area away from both feeding and resting areas. Furthermore, outdoor feeders are more exposed to detrimental external influences such as weather conditions and may attract vermin and birds. To avoid the risk of feed waste due to wetness, and to ensure comfortable conditions for pigs during feeding, feeders should be under the roof. Feeding pigs outdoors could also reduce dust levels, which is especially important when using dry feed.

Drinkers

Positioning drinkers in the OUTRUN potentially increases the use of OUTRUNs. Ocepek et al. (2020) found that drinkers in the OURUN reduced manipulation of pen-mates compared to drinkers indoors or at both locations. They argue that an increased use of the OUTRUN reduced crowding and therefore pen-mate directed behaviours. While pigs seem to prefer outdoor drinkers, this location does not necessarily improve pen hygiene (Vermeer et al., 2015; Ocepek et al., 2018). Various studies found that pigs avoid elimination close to resources such as feeders or drinkers (Watson et al., 2003; Salomon et al., 2007). The influence of drinker position and wet areas around drinkers on the pig's choice of elimination area remains unclear and needs further research considering particularly interactions with space allowance and floor type. Providing drinkers in the OUTRUN (Fig. 1) may still attract pigs to go outside, and thus reduce the activity level indoors and ensure an undisturbed indoor resting area. Yet, in colder regions, freezing has to be prevented (e.g. by heating the water pipe, having it in a frost-free place or switching to indoor drinkers during winter).

Cooling facilities

As pigs cannot sweat (Ingram, 1965), opportunities for thermoregulation may become increasingly important when considering rising summer temperatures. EU legislation (European Parliament and Council, 2018) asks for means allowing thermoregulation in the open-air area, which is specified in more detail by animal welfare legislation and private standards in some countries (Table 1).

At moderate temperature, thermoregulation occurs mainly through sensible heat loss and is affected by space (increased/decreased distance to pen-mates), floor type (e.g. bedded versus concrete floor), roofing (shaded/unshaded areas) and partition type (high/low airflows). However, sensible heat loss requires a temperature gradient between the pig's surface and the surroundings. Thus, at increasing temperatures, pigs need to increase their evaporative heat loss. The most natural and effective way to do this is a mud wallow, combining long-term evaporative cooling and protection from sunburn and ectoparasites (Bracke, 2011). However, providing a mud wallow is challenging in OUTRUNs in relation to hygiene and workload. Cooling with water only (through water baths or showers) is a viable alternative (Fig. 1). Both methods were effective in reducing heat stress and improving daily gain at about 28 °C (Huynh et al., 2006). Olsen et al. (2001) reported hygiene problems when using water-filled bathtubs. Huynh et al. (2006) found increased elimination (over 60% of defaecations and urinations) in the water bath in pens without OUTRUNs compared to pens with OUTRUNs (i.e. extra space). This indicates a relation between elimination in the water bath and the pigs' inability to divide the pen into functional areas, possibly due to limited space. Providing showers proved to reduce pen soiling through changed lying behaviour in indoor systems. Additionally, the diluting effect of water, combined with less soiling, could reduce NH_3 emissions (Jeppsson et al., 2021). Whether these environmentally beneficial effects also apply for showers in OUTRUNs still needs scientific confirmation. Moreover, additional water in the manure increases the required capacity for manure storage and application to the field.

Partitions

Some national and private standards ask for an unobstructed view for pigs, i.e. open partitions at the outer end of the OUTRUN (Table 1). However, the benefit of an unobstructed view for pigs has not yet been studied to our knowledge and should consider species-specific sensory perception. Open partitions would, however, affect the climate in OUTRUNs by ensuring a higher air change. An increased air change will reduce humidity, which supports evaporative heat loss especially when facilities to wet the skin are available. A combination of closed and open partitions allows the pigs to choose between areas with high or low air flow, thus increasing the pig's possibilities for thermoregulation.

Open pen partitions have an indirect effect on elimination behaviour, by making the area unattractive for lying (Jackson et al., 2020). However, this effect could change at high temperatures, as areas with higher air flow attract pigs for thermoregulation. The social contact with neighbouring groups through open partitions could also play a role in pigs' choice of elimination areas. Watson et al. (2003) found more elimination along the border to neighbouring groups in free-range pigs and suggest that this was due to territorial behaviour. In contrast, Allwin et al. (2016) observed no territorial behaviour in wild pigs. The distribution of elimination in a paddock may rather be affected by the distance to resources (e.g. feeder) as shown by Salomon et al. (2007). Open pen partitions alone do not guarantee that elimination will be limited to this area. Additionally, higher air changes would increase NH_3 emissions from soiled areas.

Solid partitions within the pen can help to structure functional areas, e.g. by keeping bedding material in their designated locations and preventing manure from being spread. Pigs need hiding walls to retreat behind in case of aggressive interactions and like to lie down along a wall protected from draughts (Jackson et al., 2020). Nevertheless, partitions within a pen should not obstruct pigs' locomotion or mechanical manure removal, which is crucial for low NH_3 emissions.

Conclusions

Although EU organic legislation provides a common framework for the design of OUTRUNs as exercise areas allowing exploration, rooting and elimination (Table 1), we need to be aware of the large variation across farms and countries. Moreover, some regulations and standards still lack scientific evidence. In this review, we describe how behavioural needs and environmental requirements for reduced NH_3 emissions can be taken into account when designing OUTRUNs for organic growing-finishing pigs. OUTRUNs offer a variety of possibilities for separating functional areas for exploration, resting, thermoregulation and elimination. In particular, additional resources may increase the attractiveness and activity in the OUTRUN. They offer opportunities for choosing between climatic conditions, which may not only create a greater sense of autonomy of the animals but also positively influence their thermal well-being. Due to the urgent need to reduce ammonia emissions, the extent of soiled areas on organic farms with higher space allowance compared to conventional housing must be given special attention. An OUTRUN design that accounts for the separation of functional areas can help to reduce the soiled surface and associated emissions.

More research on OUTRUNs is needed specifically regarding:

(1) The influence of shape, degree of roofing, feeder location and provision of brushes on pig behaviour and use of functional areas.
(2) How pigs' choice of where to eliminate is influenced in particular by open pen partitions, drinker position, showers or wet areas.
(3) The potential benefit of exposure to natural climatic conditions (rain, sunshine, etc., unobstructed view) for pig welfare.
(4) The interaction of various influences in the outdoor climate on soiling and ammonia emissions, which entails extended research and measurement of ammonia emissions in the OUTRUN.

Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.animal.2021.100435.

Ethics approval

Not applicable.

Data and model availability statement

None of the data were deposited in an official repository. The data that support the study findings (list of publications from the literature search) are available to reviewers upon request.

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Declaration of interest

None.

Acknowledgements

This paper is part of the POWER project coordinated by Anne Grete Kongsted. The authors would like to thank Sandra Edwards for her helpful comments and language revision. Open access funding is provided by University of Natural Resources and Life Sciences, Vienna (BOKU).

Financial support statement

The financial support for the POWER project is provided by transnational funding bodies, being partners of the H2020 ERA-net project, CORE Organic Cofund, and the cofund from the European Commission.

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