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Combining several indicators to assess the effectiveness of tailor-made health plans in pig farms

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Abstract

A tailor-made health plan is a set of recommendations for a farmer to achieve and maintain a high health and welfare status. Tailored to each farm, it is intended to be an effective way of triggering change. This study aimed to assess the effectiveness of tailor-made health plans in pig farms, designed in various situations after a systematic biosecurity and herd health audit. An intervention study was carried out in 20 farrow-to-finish pig farms. An initial standardized audit and discussion between the farm veterinarian and the farmer resulted in a specific plan. Compliance with recommendations was monitored during 8 months. Changes in health, performances and antimicrobial use were monitored. We defined two categories of plans: i) 14 plans targeting a given health disorder present in a farm; ii) 17 plans to improve prevention, not targeting a specific health disorder (a farm could have both types of plans). A small number of priority recommendations were made per farm. In 18 farms, farmers implemented 1 to 4 recommendations (none in 2 farms). Of the 17 non-disorder-specific plans, 11 were considered effective (>50% recommendations implemented), 3 intermediate (at least one but less than half of the recommendations implemented) and 3 ineffective (no implementation). Of the 14 disorder-specific plans, 9 were followed with full or good compliance (>50% recommendations implemented), 2 with intermediate compliance (1 recommendation implemented out of 2) and 3 with no compliance (no recommendation implemented). When at least one recommendation was implemented, change in clinical, performance and antimicrobial use indicators was assessed if a biological association with the disorder was deemed plausible and if their initial value showed room for improvement. Improvement was evidenced 4/9, 1/6 and 1/6 times for these indicators, respectively. Independently, veterinarians concluded that 8/14 plans were effective. Overall, tailor-made health plans were effective in triggering changes in farm management. Three key points were identified for future assessments of the effectiveness of tailor-made health plans. Compliance should be the first indicator of assessment. Outcome indicators and their monitoring periods should be adapted to each farm and to the targeted health disorder. Indicators should be combined to have a holistic description of the evolution of a health disorder. Further research is needed to identify how to select indicators to combine and how to combine them, according to health disorders.

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Introduction

Achieving and maintaining a high pig health status is essential for pig farm sustainability. Keeping healthy pigs in farms can avoid major economic losses at a farm level but also for the pig industry thanks to improved performances, reduced mortality and treatment costs (Nathues et al., 2017; Maes et al., 2018). For instance, Porcine Reproductive and Respiratory Syndrome virus (PPRSv) cost for the pig industry in the US was estimated at $664 million annually (Holtkamp et al., 2013). Infectious diseases are very frequent in pig farms and their prevention and cure contribute to animal welfare (Fraser et al., 1997; OIE, 2021) and public health (Lun et al., 2007). Moreover, reducing the risk of infectious diseases is a concern for European consumers (Clark et al., 2019).

In pig farms, vaccination and biosecurity are the two main tools to prevent infectious diseases. Biosecurity is the application of measures aiming to reduce the risk of introduction and spread of pathogens (Alarcón et al., 2021). Biosecurity is a topic frequently discussed with farmers, with increased concern since the risk of African swine fever spread in Europe (Dixon et al., 2019). The prevention of the introduction and the spread of pathogens in farms refer to external and internal biosecurity, respectively. Biosecurity measures refer to segregation, hygiene, or management procedures excluding medically effective feed additives and preventive/curative treatment of animals (Huber et al., 2022). Biosecurity audits can be performed considering all the possible biosecurity measures or only the ones related to a specific disease (Silva et al., 2018). Biosecurity audits may lead to the formulation of recommendations by veterinarians targeting the biosecurity measures that are considered essential for the farm but were not implemented.

Recommendations of veterinarians aim at improving a health status or at preventing its potential deterioration. However, no health improvement can be expected if farmers do not comply with formulated recommendations. Farmers may – or may not - comply with recommendations according to the cost of the measures (Alarcon et al., 2014), the amount of work required (Garforth et al., 2013), the risk perception they have (Simon-Grifé et al., 2013) or their personality traits (Racicot et al., 2012; Delpont et al., 2021). Furthermore, farmers are more likely to comply with recommendations when they perceive their benefits (Valeeva et al., 2011; Garforth et al., 2013; Renault et al., 2021). Veterinarians thus face the challenges of formulating recommendations that are perceived relevant by farmers and to communicate them effectively.

Tailor-made health and welfare plans include farm-specific recommendations adapted to the farm context and are more likely to meet farmers' objectives (Kristensen & Jakobsen, 2011; Lam et al., 2011; Garforth, 2015; Blanco-Penedo et al., 2019; Bard et al., 2019). They are formulated by herd veterinarians after analysing the specific farm context (*i.e.* health situation, risks, performances and socio-economic situation). In dairy cow studies, tailor-made health plans are aimed at improving different health conditions that could differ between farms (*e.g.* udder health, reproduction or locomotor disorders) (Ivemeyer et al., 2012; Tremetsberger et al., 2015; Duval et al., 2018; Sjöström et al., 2019; Svensson et al., 2019). In pig and poultry studies, most tailor-made health plans are aimed primarily at reducing antimicrobial use, without jeopardizing health, technical or economic performances (Rojo-Gimeno et al., 2016; Postma et al., 2017; Collineau et al., 2017; Roskam et al., 2019; Raasch et al., 2020). The assessment of the effectiveness of health plans is necessary to provide feedback on their benefits to farmers and herd veterinarians. However, neither a clear definition of the effectiveness of a health plan nor a reference method to assess it have been proposed so far.

In order to assess the effectiveness of a tailor-made health plan, Tremetsberger and Winckler (2015) proposed to consider "the degree of implementation […] as a measure of success" and to monitor indicators related to health evolutions. A tailor-made health plan mainly aims to improve herd health, and other parameters may evolve jointly (e.g. drug use, productivity). In on-farm pig studies, the effectiveness was assessed considering the decrease of antimicrobial use combined with an absence of deterioration of i) disease incidence, ii) net farm profit per sow per year or iii) technical performances (Postma et al., 2017; Collineau et al., 2017; Raasch et al., 2020). No study combined all these types of indicators. A holistic description of the effectiveness of tailor-made health plans thus requires to combine several complementary indicators.

This study aimed at assessing the effectiveness of tailor-made health plans in pig farms, designed in a variety of situations after a systematic audit on biosecurity and herd health. In an intervention study, tailor-made health plans were developed and compliance with recommendations, health, technical performances and antimicrobial use were monitored. We here assumed that a combination of compliance assessment and of several indicators at farm level can be appropriate to assess the effectiveness of farm specific health plans. Since there is no reference method to assess effectiveness, seven methods were used and compared to identify key points for developing future assessments in farms.

Material and Methods

Intervention study design

An intervention study was conducted in 20 farrow-to-finish French pig farms with the aim to assess the effectiveness of Tailor-Made Health Plans (TMHP). Figure 1 provides a synthetic overview of the study design. The intervention in each farm was based on the collection of a set of data during an initial farm visit, leading to the formulation of recommendations by veterinarians at the end of the visit. Collected data were: i) results of a systematic biosecurity audit, ii) description of management practices not related to biosecurity (including other measures promoting health than biosecurity, such as feeding, housing and reproduction), iii) observed clinical signs at every physiological stage, iv) past records of health disorders, v) antimicrobial purchases during the previous year and vi) records of technical performances during the previous year. A TMHP was a set of tailor-made recommendations formulated by the veterinarian, for the farm aiming at improving pig health. Three visits were included in a prospective longitudinal study to initiate and follow-up the TMHP: i) visit 1 was performed to describe the initial farm context by collecting data then to formulate recommendations, ii) visit 2 was performed to assess compliance with recommendations formulated at visit 1, iii) visit 3 was performed to collect the same data as at the visit 1 and carry out an update on compliance. After visit 3, the opinion of the farm's veterinarian was asked with regard to the evolution of the health situation in the farm. Standardized indicators were calculated for health, technical performances and antimicrobial use. Indicators were estimated at visits 1 and 3 to assess possible evolutions. The effectiveness of TMHP was assessed after visit 3 with seven methods relying on compliance with recommendations, evolutions of indicators and veterinarians' opinion. Visit 2 and 3 occurred around four and eight months after visit 1 respectively. Farms were visited between December 2020 and December 2021.

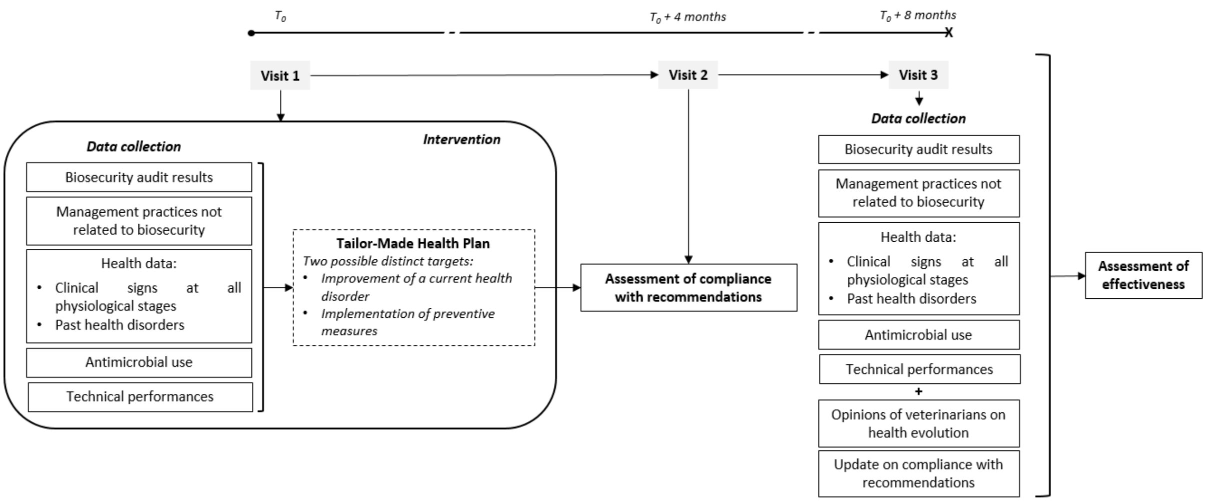

Figure 1 - Design of the intervention study to assess the effectiveness of tailor-made health plans in pig farms

Farm recruitment

Twenty farrow-to-finish pig farms were recruited in western France.Veterinarians from 10 different practices were asked to recruit farms in which the formulation of a TMHP was deemed useful to improve biosecurity or animal health. A total of 14 veterinarians selected 20 farms (six veterinarians selected two farms). Two farms were organic and 18 were conventional. Seven farms out the 18 conventional farms had other specifications: i) four farms were Label Rouge (République Française, 2017), ii) two farms had antibiotic-free pigs from birth and iii) one farm had antibiotic-free pigs from 42 days of age. The 20 farms were related to 10 different cooperatives.

Biosecurity audit

A biosecurity audit was conceived for the HealthyLivestock project and was named BiosEcurity risk Assessment Tool (BEAT; see Appendix with BEAT tables 1 to 6). The objective of the BEAT was to describe systematically implemented *vs* non-implemented biosecurity measures, and to identify the ones needing improvement and considered critical by the veterinarian for a given farm. The BEAT was conceived considering three farm zones (FAO): i) public: outside the professional zone, ii) professional: farm zone dedicated to the movement of authorized persons and vehicles and the storage or transit of incoming and outgoing products, iii) herd: farm zone limited to housing facilities where pigs are kept. Transitions between zones were also considered: transition 1, from the public zone to the professional zone and transition 2, from the professional zone to the herd zone. A total of 97 biosecurity measures were assessed and distributed in the five zones: public (n=12), transition 1 (n=24), professional (n=12), transition 2 (n=19) and herd (n=30). Internal and external biosecurity were assessed considering introduction and circulation of pathogens through i) neighbourhood activities, ii) external vehicles, iii) rendering management, iv) visitors, v) staff, vi) farm animals, vii) wildlife, viii) feeding, ix) unnecessary access, x) manure management, xi) cleaning-disinfection, xii) purchases and xiii) shared equipment. In a few farms, some biosecurity measures were not relevant in their given context and were thus not assessed (for instance quarantine for farms with self-replacement of gilts).

Each initial audit was systematically performed through i) a face-to-face interview with the farmer, the farm veterinarian and the first author, and ii) a farm inspection (visit 1). The audit was repeated at visit 3 by the first author through a face-to-face interview with the farmer and a farm inspection. Results of the audits were recorded in an Excel template (available from the authors upon request). A biosecurity measure was scored 1 when implemented and 0 otherwise.

Monitoring of indicators

Indicators were recorded or calculated to summarize clinical observations, technical performances and antimicrobial use before and after the intervention (Table 1). The monitored period depended on the indicator considered. Clinical indicators were calculated at visits 1 and 3 whereas technical performance and antimicrobial use indicators were cumulative over a period of one year (see below).

Clinical observation

Clinical indicators were designed before the visits and based on i) their ability to measure an improvement in biosecurity and ii) their specific association with infectious diseases likely to be present in pig farms in the study area. Respiratory and digestive disorders were systematically investigated at visit 1 and visit 3. Cough and sneeze counts were used to assess respiratory disorders. Faeces scoring was used to assess digestive disorders. Different physiological stages were observed (*i.e.* a total of six stages: i) gestating sows, ii) suckling piglets, iii) the youngest batch of weaned piglets, iv) the oldest batch of weaned piglets before entering the fattening unit, v) the youngest batch of fattening pigs and vi) the oldest batch of fattening pigs before being sent to the slaughterhouse).

Technical performances

Technical performance data were collected from farm records. Data were collected for i) the year preceding the intervention and ii) the on-going year period. The average daily gain (ADG) and the feed conversion ratio (FCR) in the wean-to-finish period, the mortality rate in post-weaning and fattening units, and the number of piglets weaned/sow/year (PWSY) were selected to cover the whole production cycle.

Antimicrobial use

Antimicrobial use was assessed with Defined Daily Dose for animals (DDDvet; European Medicines Agency, 2015). DDDvet were calculated from antimicrobial purchase data of the farm. DDDvet were calculated for sows, suckling piglets, weaners and fatteners for the year preceding the intervention and for the on-going year.

Collection of health documents

Past records of health disorders and vaccination protocols were collected from the veterinarians before the visit 1. Veterinarian reports, performed at least once a year per farm, were systematically collected for the year preceding the intervention. Reports of laboratory analyses or of lesions observed at the slaughterhouse were collected when available.

Formulation of Tailor-Made Health Plan

A Tailor-Made Health Plan (TMHP) was defined as a set of tailor-made recommendations at the farm level made by the farm veterinarian. Recommendations could be biosecurity measures that were not implemented by the farmer and prioritized by veterinarians considering the farm context (Levallois et al., 2022). Other recommendations than biosecurity measures could be formulated considering the farm context and in particular the presence of health disorders. Recommendations were recorded systematically by the first author.

We defined two distinct types of TMHP with: i) measures recommended to improve one specific targeted health disorder present in the farm (thereafter named $TMHP_{disorder}$) or ii) measures recommended to prevent pathogen introduction or circulation not targeting a specific disorder (thereafter named $TMHP_{prev}$). In the perspective of the assessment, we considered that only one single health disorder was targeted per $TMHP_{disorder}$. If several distinct health disorders were targeted in one farm, several $TMHP_{disorder}$ were distinguished. Therefore, for a given farm, veterinarians could either formulate i) one $TMHP_{disorder}$, ii) several $TMHP_{disorder}$, iii) one $TMHP_{prev}$, iv) one $TMHP_{disorder}$ and one $TMHP_{prev}$ or v) several $TMHP_{disorder}$ and one $TMHP_{prev}$.

Assessment of compliance with recommendations

Compliance with recommendations was assessed by the first author through face-to-face interviews with farmers at the visit 2, that occurred around four months after visit 1. TMHP recommendations were reminded to farmers. Then, farmers were asked if each recommendation had been implemented or not. If not, a reason to explain the absence of compliance was systematically asked to farmers and recorded in writing. An update on compliance was carried out at the visit 3 with the same method, around eight months after visit 1. Observations by farm inspection were performed during farm visits 2 and 3 to double check the compliance assessment when it was possible.

Categorisation and evolution of indicators

We considered that indicators could improve only if there was room for improvement at visit 1. Cut-off values were defined to determine the presence of room for improvement for each indicator (Table 2). Cut-off values for clinical indicators were defined by considering i) the distributions of observed values in all physiological stages and ii) past records of respiratory and digestive disorders in farms. These cut-off values led to three categories of severity: i) mild, ii) moderate and iii) severe (Table 1). Categories were defined considering ranges of clinical observations. For instance, a number of coughs (or sneezes) / 2 minutes / 100 animals < 1 was observed in all farms where no respiratory disorders were reportedand > 5 in all farms where important respiratory disorders were reported.. An absence of faeces scores 2 and 3 was observed in all farms where no digestive disorder was reported (cumulated percentage of 0%).. As regards technical performances, cut-off values were defined with reference values from the collected records (average performances of a company). For antimicrobial use, no reference value was available for any physiological stage: cut-off values were determined by the first quartile of the data distribution (presented in appendix, Figure A1).

There was room for improvement for:

- Clinical situation: when indicators (cough or sneeze counts, faeces scores) were classified in categories moderate or severe at visit 1.
- Technical performances: could always be improved whatever the initial situation.
- Antimicrobial use: when farm DDDvet > 0 mg/day/kg/1000 animals.
- Criteria of evolutions for indicators are defined in Table 2.
- Clinical situation: improved or deteriorated at visit 3 if indicators were classified in a lower or a higher category than at visit 1, respectively.

Table 1 - Description of indicators used to monitor evolution of health, performances and antimicrobial use after the formulation of tailor-made health plans, based on a systematic audit of biosecurity and herd health in 20 farrow-to-finish pig farms

Type of indicator	Indicator	Unit	Method description	Categories of severity 1: mild	 2: moderate	 3: severe
Clinical observations	Cough count *or* Sneeze count	Number / 2 minutes / 100 animals	Counting three times for two minutes for each physiological stage. Cough (or sneeze) counts = $\sum \text{coughs (or sneezes)}\ counted * \frac{100}{Number\ of\ observed\ animals} * \frac{1}{3}$	<1 count / 2 minutes / 100 animals	[1 ; 5[counts / 2 minutes / 100 animals	≥ 5 counts / 2 minutes / 100 animals
	Faeces score	-	Attribution of a faeces score at a pen scale from 1 to 4: Score 0: absence of diarrhoea (firm faeces) Score 1: absence of diarrhoea but presence of some water (soft faeces) Score 2: presence of diarrhoea (very soft faeces) Score 3: important diarrhoea (liquid faeces). Percentage of occurrence of each faeces score (Score %) was calculated at each visit: $Score\ \% = \frac{Number\ of\ a\ given\ faeces\ score}{Total\ number\ of\ faeces\ score} * 100$	0% of scores 2 and 3 accumulated	]0; 20[% of scores 2 and 3 accumulated	≥ 20% of scores 2 and 3 accumulated
Technical performances	ADG[1] FCR[2] Mortality PWSY[3]	g/day kg/kg % Number of piglets weaned/sow/year	Collected from technical documents (wean-to-finish period) Collected from technical documents (post-weaning and fattening periods) Collected from technical documents	Categories of severity only concerned clinical observations		
Antimicrobial use	DDDvet[4]	mg/day/kg	Defined Daily Dose for animals (DDDvet; European Medicines Agency, 2015) = $\sum_{all\ antimicrobials\ used} \frac{active\ substance\ weight}{dose * animal\ weight\ of\ a\ category}$	Categories of severity only concerned clinical observations		

1: ADG = Average Daily Gain, 2: FCR = Feed Conversion Ratio, 3: PWSY = Piglets Weaned per Sow per Year, 4: DDDvet = Defined Daily Dose for animals

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- Technical performances: improved or deteriorated at visit 3 if the value of their indicators at visit 1 increased or decreased (ADG, PWSY) and decreased or increased (FCR, mortality) by 2%, respectively.
- Antimicrobial use: improved or deteriorated if the DDDvet decreased or increased by 10% between the two monitored periods..

For all types of indicators, a *statu quo* was defined when there was neither an improvement nor a deterioration.

Veterinarian's opinion on the evolution of health disorders

Veterinarians' opinions on the evolution of health disorders were recorded after the visit 3, independently of the visit. They were orally asked by phone or face-to-face. Veterinarians were asked if there was a health disorder improvement, *statu quo* or deterioration according to their routine health monitoring of the farm through the period since visit 1. All their opinions were recorded in writing. Our results of the assessment of compliance and indicators were not shared with veterinarians at this time of the study.

Table 2 - Indicators and criteria used to define room for improvement at visit 1 and to characterize evolutions between visits 1 and 3 (*i.e.* improvement or deterioration; see Table 1 for the definitions of categories) in 20 farrow-to-finish pig farms

Type of indicator	Indicator (unit)	Baseline	Presence of room for improvement at the initial situation	Improvement criteria	Deterioration criteria
Clinical observations	Cough count (count/2minutes/100animals)	Visit 1	Indicator classified in categories 2 or 3 at visit 1	Indicator classified in a lower category at visit 3 than at visit 1	Indicator classified in a higher category at visit 3 than at visit 1
	Sneeze count (count/2minutes/100animals)	Visit 1			
	Faeces score (%)	Visit 1			
Technical performances	ADG[1] (g/day)	Year before intervention	-[5]	Relative increase by 2%	Relative decrease by 2%
	FCR[2] (kg/kg)		-	Relative decrease by 2%	Relative increase by 2%
	Mortality (%)		-	Decrease by 2%	Increase by 2%
	PWSY[3] (piglets weaned /sow/year)		-	Relative increase by 2%	Relative decrease by 2%
Antimicrobial use	DDDvet[4] sows (mg/day/kg/1000 animals)		>0	Relative decrease by 10%	Relative increase by 10%
	DDDvet piglets		>0		
	DDDvet weaners		>0		
	DDDvet fatteners		>0		

1: ADG = Average Daily Gain, 2: FCR = Feed Conversion Ratio, 3: PWSY = Piglets Weaned per Sow per Year, 4: DDDvet = Defined Daily Dose for animals, 5: - = we considered that there was room for improvement for technical performances

Assessment of effectiveness of Tailor-Made Health Plans

In the absence of a reference method to assess the effectiveness of a TMHP, we proposed to use seven methods to identify their advantages and limitations. Figure 2 provides a description of the seven methods used. In this study, effectiveness is the observation of the expected effects of a TMHP that were: i) the improvement of a targeted health disorder and its consequences after compliance with recommendations (for a $TMHP_{disorder}$) or ii) the implementation of measures to prevent pathogen introduction or circulation (for a $TMHP_{prev}$).

On the one hand, the assessment of effectiveness for a $TMHP_{disorder}$ was based on six methods:

A. Veterinarians' opinion

B. A combination of the compliance assessment and the evolutions of clinical observations (thereafter named clinical observation method)
C. A combination of the compliance assessment and the evolutions of technical performances (thereafter named technical performance method)
D. A combination of the compliance assessment and the evolutions of antimicrobial use (thereafter named antimicrobial use method)
E. A combination of the compliance assessment and the evolutions of all selected indicators (clinical observations, technical performances and antimicrobial use; thereafter named the all-indicator method)
F. A combination of the compliance assessment and the evolutions of available indicators (allowing assessment despite missing data; thereafter named the available-indicator method)

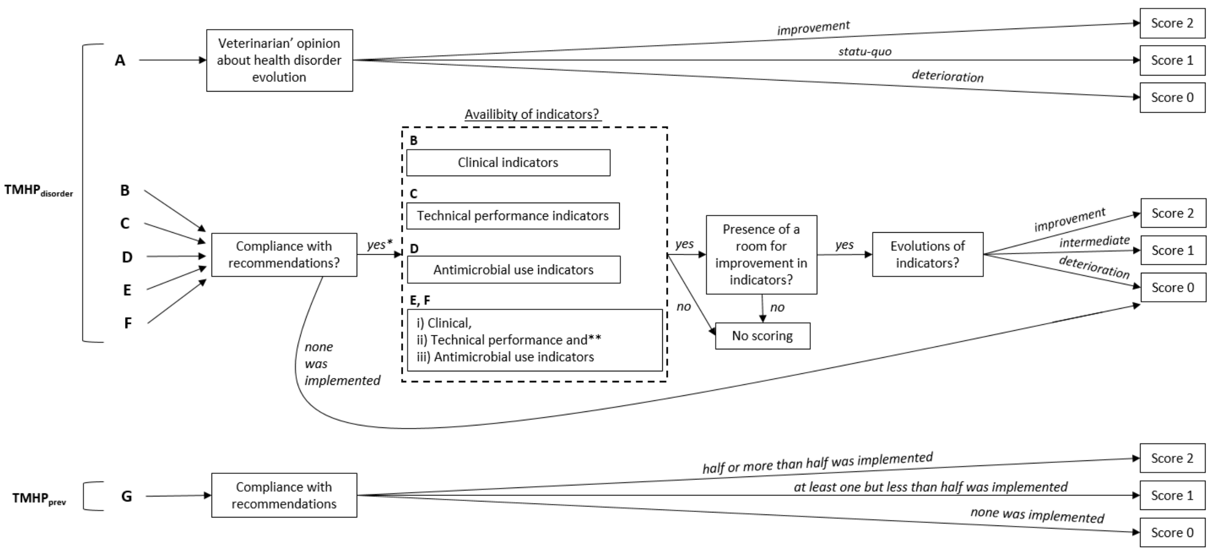

Figure 2 - Description of the methods to assess the effectiveness of tailor-made health plans (*score 2: effective; score 1: intermediate effectiveness; score 0: ineffective*) considering seven methods, six for $TMHP_{disorder}$ (*A: veterinarians' opinion; B: compliance with recommendations and evolution of clinical indicators; C: compliance with recommendations and evolution of technical performance indicators, D: compliance with recommendations and evolution of antimicrobial use indicator, E: compliance with recommendations and evolutions of all selected indicators, F: compliance with recommendations and evolutions of available indicators*) and one method G for $TMHP_{prev}$ based on compliance assessment (*: *at least one recommendation was implemented; **: difference between methods E and F as defined above*)

To be used, a method had to be feasible (available data) and biologically relevant for the given TMHP. Indicators could not be assessed in two situations. Firstly, an indicator could be unavailable in a farm: no monitoring of technical performances, no records on antimicrobial use and no animals in a given physiological stage at the time of the visit. Secondly, there could be no room for improvement according to the baseline value of the initial visit (as defined in Table 2).When one of these two particular cases occurred for clinical observation or technical performance or antimicrobial use method, no assessment was performed and consequently, no assessment was performed for the all-indicator method since data were missing. On the contrary, the available-indicator method could still be performed when at least one of the indicators was available. An indicator was considered biologically relevant for a given TMHP, when it was possible to assume that its evolution was associated with the evolution of the targeted health disorder. DDD_{vet} was considered relevant when antimicrobials were used to cure the health disorder of interest before the intervention. Indicators used to assess effectiveness could thus differ between $TMHP_{disorder}$.

On the other hand, the assessment of effectiveness for a $TMHP_{prev}$ was only based on the compliance assessment (method G). Indeed, according to the nature of recommendations (mainly targeting external biosecurity, see below), no direct effect on the available indicators could be assumed in the time frame of the study.

Whatever the method, three ranked levels of TMHP effectiveness were possible (*i.e.* i) effective, ii) intermediate or *statu quo*, iii) ineffective) and were scored 2, 1 and 0 respectively:

- $TMHP_{disorder}$ effectiveness based on veterinarians' opinions (method A):
  - Effective (score 2): improvement of the health disorder
  - *Statu quo* (score 1): no evolution of the health disorder
  - Ineffective (score 0): deterioration of the health disorder

- $TMHP_{disorder}$ effectiveness based on a combination of compliance assessment and the evolution of indicators, with each type of indicators considered separately (*i.e*. clinical observations or technical performances or antimicrobial use for methods B, C, D, respectively):
  - Effective (score 2): at least one recommendation was implemented, and at least one indicator improved and the other indicators did not deteriorate
  - Intermediate (score 1): at least one recommendation was implemented and indicators neither improved nor deteriorated
  - Ineffective (score 0):
    - no recommendation was implemented since we considered that recommendations "can only effectively improve health and welfare if they are actually implemented on-farm" (Tremetsberger & Winckler, 2015), or
    - at least one recommendation was implemented but at least one indicator deteriorated (whatever the evolutions of other indicators)

- $TMHP_{disorder}$ effectiveness based on a combination of compliance assessment and the evolution of all selected or available indicators (methods E and F):
  - Method E: this method could be performed only if all selected indicators were available. The method for assessing effectiveness was the same as for methods B, C, D but all types of selected indicators were combined.
  - Method F: this method combined all available indicators in a given farm. Method F could therefore be performed despite missing data among selected indicators. Moreover, this method was less limitative to assess effectiveness:
    - Effective (score 2): at least one recommendation was implemented and at least one indicator improved, no matter the evolution of other available indicators
    - Intermediate (score 1): at least one recommendation was implemented and at least one indicator neither improved nor deteriorated (and no indicator improved; no matter if other available indicators deteriorated)
    - Ineffective (score 0):
      - no recommendation was implemented, or
      - at least one recommendation was implemented but all available indicators deteriorated

- $TMHP_{prev}$ effectiveness (method G):
  - Effective (score 2): half or more than half of the recommendations were implemented
  - Intermediate (score 1): at least one but less than half of the recommendations were implemented
  - Ineffective (score 0): no recommendation was implemented

Data analyses

Regarding the results of biosecurity audits, the percentage of implemented biosecurity measures was calculated in each zone.

Results of the different methods to score effectiveness of the $TMHP_{disorder}$ were compared by visual inspection. The possible use of each method, the scores, and the concordance or discrepancies between methods were displayed.

Results

Farm characteristics

Farm size ranged from 70 to 800 sows with an average number of 244 sows. The batch management ranged between a 1-week system (a batch farrowing every week) and a 7-week system (7-week interval between farrowing of two consecutive batches). All farms were included in the follow-up (visits 2 and 3). One farmer in charge of the animals was replaced by another one during the study period.

Initial situation

Biosecurity

At visit 1, percentages of implemented biosecurity measures according to the five farm zones were: 44.5 ± 12.2% (public), 56.6 ± 10.0% (transition public-professional), 60.3 ± 10.9% (professional), 58.6 ± 14.9% (transition professional-herd), 72.4 ± 10.2% (herd) (Figure 3). On average, 34.9 ± 7.2 biosecurity measures (*i.e.* 38.3 ± 7.9%) were not implemented at visit 1 when all zones were considered.

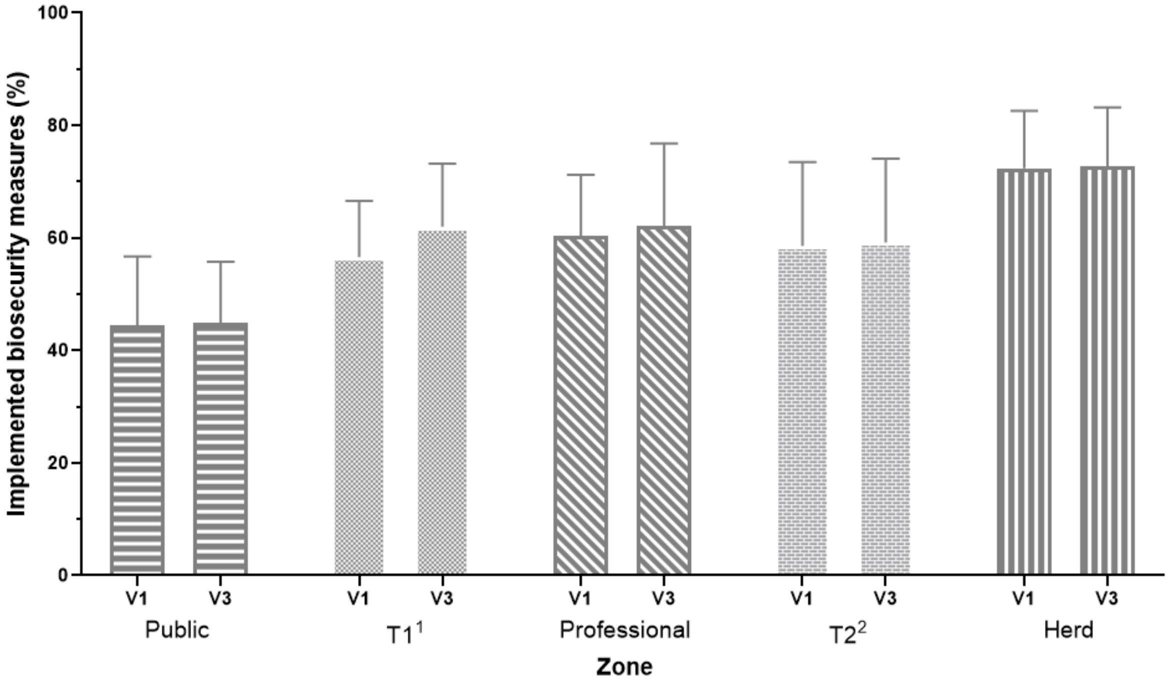

Figure 3 - Percentage of biosecurity measures implemented at visits 1 and 3 (before and after the formulation of tailor-made health plans) in 20 farrow-to-finish pig farms according the five farm zones (1: first transition zone between public and professional zones; 2: second transition zone between professional and herd zones)

Recommendations

The number of recommendations per farm ranged from 1 to 6 with a total of 69 recommendations. On average, 3.5 ± 1.7 recommendations were formulated per farm. A total of 40 recommendations were related to biosecurity and 29 recommendations were related to antimicrobial use, environmental enrichment, feeding, housing facilities, laboratory analyses, management practices or vaccines. An overview of these recommendations grouped by categories is provided in Table 3. The most frequent biosecurity recommendations concerned the public-professional transition zone (n=19). These biosecurity recommendations mainly targeted at implementing measures related to hygiene lock (n=9) and at fencing the professional zone (n=9). Recommendations not related to biosecurity mainly focused on implementing a new vaccination scheme (n=10), or on advising laboratory analyses (n=6).

Table 3 - Distribution of the recommendations formulated in tailor-made health plans based on a systematic audit of biosecurity and herd health, and implemented in 20 farrow-to-finish pig farms

Categories of recommendations in the tailor-made health plan	Number of formulated recommendations	Number of implemented recommendations
Biosecurity	**40**	**22**
Public zone	**1**	**1**
Maintaining in the public zone persons and vehicles with unnecessary access to the professional zone	1	1
Transition public-professional zone	**19**	**9**
Prevention of the contamination of the professional zone due to unnecessary access	1	1
Prevention of the contamination of the professional zone by farmers or visitors	9	4
Prevention of the contamination of the professional zone by wild animals	9	4
Professional zone	**3**	**2**
Prevention of the contamination associated to the elimination of dead animals	1	0
Prevention of the persistency of pathogens in the professional zone	2	2
Transition professional-herd zone	**6**	**5**
Prevention of the introduction of pathogens by purchased animals	2	2
Prevention of the introduction of pathogens by farmers	4	3
Herd zone	**11**	**5**
Prevention of the transmission of pathogens by farmers or visitors	2	0
Prevention of the transmission of pathogen between animals of different ages	1	0
Prevention of transmission of pathogens due to infected building	3	3
Reduction of situations at risk due to heterogeneous herd immunity	4	2
Reduction of situations at risk due to high loads of pathogens	1	0
Other recommendations	**29**	**20**
Antimicrobial use: individual treatment	1	1
Environmental enrichment	5	1
Feeding	2	2
Housing facilities : temperature or ventilation parameters	2	1
Laboratory analyses	6	6
Management practices	3	0
Vaccines : implementation of a new vaccination scheme	10	9

Tailor-Made Health Plans

The number of recommendations per type of tailor-made health plans (TMPH) ranged from 1 to 4 for $TMHP_{disorder}$ (targeting a health disorder to improve) and from 1 to 5 for $TMHP_{prev}$ (targeting preventive measures to implement). Table 4 provides a description of the type of TMHP per farm and the number of formulated and implemented recommendations. Fourteen $TMHP_{disorder}$ and seventeen $TMHP_{prev}$ were formulated. One farm had two $TMHP_{disorder}$ and ten farms had both types of TMHP (one $TMHP_{disorder}$ and one $TMHP_{prev}$). The mean number of recommendations was higher in farms that had both $TMHP_{prev}$ and $TMHP_{disorder}$ (4.4 ± 0.9 recommendations) than for farms that had only one $TMHP_{prev}$ or one $TMHP_{disorder}$ (respectively 2.7 ± 0.9 and 1.7 ± 0.9 recommendations).

Table 4 - Number of formulated and implemented recommendations per farms per tailor-made health plans targeting a health disorder to improve ($TMHP_{disorder}$) or preventive measures to implement ($TMHP_{prev}$)

	Number of farms	**Number of recommendations per farm (Mean ± standard-deviation)**		**Compliance (%) (Mean ± standard-deviation)**
		Formulated	**Implemented**	
$TMHP_{disorder}$[1]	3	1.7 ± 0.9	1.3 ± 0.6	88.9 ± 19.2
$TMHP_{prev}$[2]	7	2.7 ± 0.9	1.4 ± 1.3	51.4 ± 36.9
Both[3]	10	4.4 ± 0.9	2.7 ± 1.2	58.7 ± 25.8
$TMHP_{disorder}$		*1.8 ± 0.8*	*1.2 ± 0.9*	*64.2 ± 39.3*
$TMHP_{prev}$		*2.6 ± 0.8*	*1.5 ± 1.1*	*52.7 ± 34.7*

1: $TMHP_{disorder}$ = Tailor-made health plan to improve a health disorder, 2: $TMHP_{prev}$ = Tailor-made health plan to improve farm prevention, 3: Farmer concerned by a tailor-made health plan to improve a health disorder and a tailor-made health plan to improve prevention. One of these 10 farms was concerned by two $TMHP_{disorder}$ and one $TMHP_{prev}$

After intervention

Changes in biosecurity

The evolutions of the percentage of implemented biosecurity measures are presented in Figure 3. Major improvements in biosecurity observed at the visit 3 concerned the public-professional transition zone (with on average 1.3 additional measures implemented after intervention). The most frequent implemented biosecurity measures were the perimeter fences around the professional zone (4 farms) or hygiene locks (4 farms).

All the implemented measures at the visit 1 were still implemented at the visit 3 in 16 out of the 20 farms. For four farms, there was a decrease in the number of implemented biosecurity measures at visit 3: in three farms one or two measures were temporarily suspended and in one farm nine measures were not implemented anymore. For this latter farm, the farmer at visit 3 was not the one in charge of the animals at visit 1.

Compliance

The number of recommendations formulated, implemented or planned to be implemented in the future at visit 2 is provided for each farm in Figure 4. The number of implemented recommendations at visit 2 ranged from 0 to 4 per farm. At least one recommendation was implemented in 18 farms out of 20. Six farmers implemented one recommendation, whereas 12 farmers implemented two or more recommendations. Overall, the total number of implemented recommendations per zone and per category is described in Table 3.

Table 4 shows for each type of TMHP the numbers of implemented recommendations per farm (mean ± standard deviation) as well as the compliance percentage (percent of implemented recommendations out of formulated recommendations). The compliance was higher in farms concerned by only $TMHP_{disorder}$ (88.9 ± 19.2%) than in farms concerned by i) both $TMHP_{disorder}$ and $TMHP_{prev}$ (58.7 ± 25.8%) or ii) only $TMHP_{prev}$ (51.4 ± 36.9%). There was no compliance with any recommendations for three $TMHP_{disorder}$, a compliance with half or more than half of the recommendations (but not all) for five $TMHP_{disorder}$ and a compliance for all the recommendations for six $TMHP_{disorder}$.

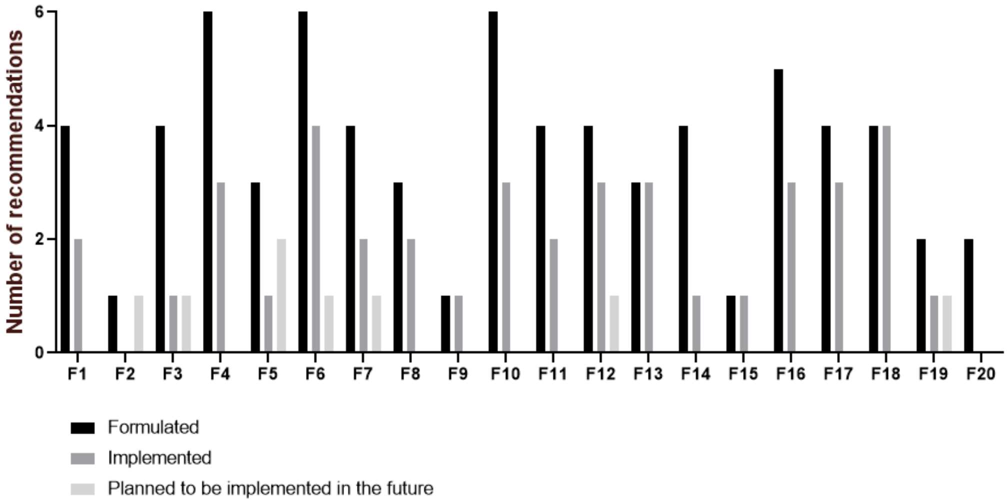

Figure 4 - Number of recommendations formulated in tailor-made health plans, implemented and planned to be implemented after visit 2 in 20 farrow-to-finish pig farms

For $TMHP_{prev}$, unwillingness and lack of time were the most frequent reasons to explain an incomplete compliance (Table 5). For $TMHP_{disorder}$, feasibility and lack of time were the most frequent reasons to explain an incomplete compliance. Some of the recommendations were planned to be implemented in the future but were not implemented at visit 2 and 3. They were all preventive measures. Despite farmers' willingness, lack of time (for 6 recommendations in 5 plans) or lack of money (for 2 recommendations in 2 plans) prevented them for implementing measures at visit 3.

Table 5 - Description of the reasons of an incomplete compliance to recommendations in farms

	$TMHP_{disorder}$[1]	$TMHP_{prev}$[2]
Number of plan with an incomplete compliance	8	14
Total number of plans	14	17
Reasons of non-full compliance		
Feasibility	3	1
Lack of money	1	3
Lack of time	3	5
Unwillingness	1	5

1: $TMHP_{disorder}$ = Tailor-made health plan to improve a health disorder, 2: $TMHP_{prev}$ = Tailor-made health plan to improve farm prevention

Evolutions of indicators between visits 1 and 3

Clinical observations considering health disorder to improve

Five farms were affected by respiratory disorders targeted to be improved. Among them, at least one respiratory indicators (cough and sneeze counts) improved in four farms; both indicators neither improved nor deteriorated (*i.e. statu quo*) in one farm.

Seven farms were affected by digestive disorders targeted to be improved. Digestive indicators (faeces scores) improved in two farms and deteriorated in one farm. The cumulated percentage of faeces scores 2 and 3 at visit 1 was 0% in three farms: there was no room for improvement in these farms (despite the health plan formulated by the veterinarians targeted a digestive disorder). Faeces score could not be assessed in one farm since piglets were not yet born at the time of the visit.

Two farms were affected by health disorders that could not be assessed with the clinical observations selected when the protocol was designed. One farm was affected by tail-biting in fattening units and one farm was affected by neurological and locomotion disorders related to *Streptococcus suis*.

Technical performances in farms where the plan targeted a health disorder to improve

ADG improved in two farms and deteriorated in three farms. FCR improved in two farms, did not improve nor deteriorate in one farm and deteriorated in two farms. Evolutions of ADG and FCR would have been relevant in five out of the 13 farms concerned by a $TMHP_{disorder}$ but could not be assessed since they were not monitored by farmers. Indicators of technical performances at the farm level are presented in appendix (Table A1).

Antimicrobial use in farms where the plan targeted a health disorder to improve

Antimicrobial use targeting a health disorder of interest decreased in one farm, neither decreased nor increased in one farm and increased in four farms according to DDDvet. Evolutions of DDDvet would have been relevant in four other farms but could not be assessed since they were not provided by veterinarians.

Effectiveness of Tailor-Made Health Plans

Table 6 displays the assessment of the effectiveness of the 14 $TMHP_{disorder}$ according to the six methods A, B, C, D, E and F. It describes the compliance with recommendations, the evolution of indicators between visits 1 and 3 and the scores of effectiveness. Table A2 (appendix) describes the type of health disorders to improve per $TMHP_{disorder}$ and the values of indicators allowing to define the evolutions of indicators (*i.e.* improvement, *statu quo*, deterioration).

- Method A – Veterinarians' opinion: eight $TMHP_{disorder}$ were effective, one presented a *statu quo* of the health disorder evolution and five were ineffective.
- Method B - Clinical observation method: four $TMHP_{disorder}$ were effective, one had an intermediate effectiveness and four were ineffective. Effectiveness could not be assessed for five $TMHP_{disorder}$ with method B for different reasons: no clinical indicator initially selected was relevant to show an improvement in the targeted health disorder in one farm; there was no room for improvement at visit 1 in three farms according to the baseline value of clinical indicators; clinical indicator could not be monitored in one farm (no animals were present at the targeted physiological stage).
- Method C - Technical performance method: one $TMHP_{disorder}$ was effective and five were ineffective. Effectiveness could not be assessed for four $TMHP_{disorder}$ with method C since technical performances could not be provided by farmers. Technical performance indicators were not relevant for four farms where the health disorder concerned a physiological stage not monitored.
- Method D - Antimicrobial use method: one $TMHP_{disorder}$ was effective, one had an intermediate effectiveness and five were ineffective. Effectiveness could not be assessed for eight $TMHP_{disorder}$ for different reasons: antimicrobial use could not be provided by veterinarians in four farms; no antimicrobials were given in three farms before the intervention, despite of the presence of an health disorder
- Method E – All-indicator method (clinical observations, technical performances and antimicrobial use): five $TMHP_{disorder}$ were ineffective. Effectiveness could not be assessed for nine $TMHP_{disorder}$ since at least one indicator of the methods B, C and D was not assessed (for the reasons given above).
- Method F – Available-indicator method: seven $TMHP_{disorder}$ were effective and five were ineffective. Effectiveness could not be assessed for two $TMHP_{disorder}$ for different reasons: i) clinical indicator informed that there was no room for improvement at visit 1, and neither technical performance data nor antimicrobial use data were provided; ii) clinical indicator could not be assessed (no animals were present at the targeted physiological stage), technical performances were not relevant (since target animals were suckling piglets whereas indicators concerned pigs from wean-to-finish) and antimicrobial use data were not provided.

The number of times a method could be used differed widely between methods A, B, C, D, E and F:

- The most used methods were the veterinarians' opinion (A), the available-indicator method (F) and the clinical observation method (B) (14, 12 and 9 times out of 14, respectively).
- The least used method were the all-indicator (E), technical performance (C) and antimicrobial use (D) methods (4, 6 and 7 times out of 14, respectively).
- From 1 to 6 methods could be used to assess the effectiveness of a $TMHP_{disorder}$.
- All the relevant methods could be used for four $TMHP_{disorder}$.

Table 6 - Assessment of the effectiveness of 14 tailor-made health plans targeting a health disorder to improve (*TMHP*$_{disorder}$) according to six methods (*A: veterinarians' opinion; B: compliance with recommendation and evolution of clinical indicators; C: compliance with recommendation and evolution of technical performance indicators, D: compliance with recommendation and evolution of antimicrobial use indicator, E: compliance with recommendations and evolutions of all selected indicators; F: compliance with recommendations and evolutions of available indicators*). Result for each method: *2: effective, 1: intermediate effectiveness; 0: ineffective* (for definitions, see text)

	Indicators to assess effectiveness							**Results of the methods to assess effectiveness**					
Farm and TMHP$_{disorder}$	**Compliance proportion**	**Cough count**	**Sneeze count**	**Faeces score**	**ADG[1]**	**FCR[2]**	**DDD vet[3]**	**A**	**B**	**C**	**D**	**E**	**F**
F1	1/1	Improved[4]	Improved	-[5]	NA[6]	NA	NRI[7]	2	2	NS[8]	NS	NS	2
F3	0/1	Improved	Improved	-	Deteriorated	Deteriorated	NRI	0	0	0	NS	0	0
F4	3/4	-	-	NRI	NA	NA	Deteriorated	2	NS	NS	0	NS	0
F6	1/1	-	-	Improved	-	-	Deteriorated	0	2	-	0	0	2
F8	2/3	-	-	NRI	-	-	Deteriorated	2	NS	-	0	NS	0
F9	1/1	-	-	-	Deteriorated	Improved	Improved	2	NS	0	2	NS	2
F10a	2/3	Improved	*Statu quo*	-	NA	NA	NRI	2	2	NS	NS	NS	2
F10b	0/1	-	-	Improved	-	-	Deteriorated	0	0	-	0	0	0
F11	2/2	-	-	NRI	NA	NA	NA	1	NS	NS	NS	NS	NS
F14	0/1	-	-	-	NA	NA	NRI	0	0	0	0	0	0
F15	1/1	Improved	*Statu quo*	-	Deteriorated	*Statu quo*	*Statu quo*	2	2	0	1	0	2
F16	1/2	-	-	Deteriorated[4]	Improved	Deteriorated	NA	0	0	0	NS	NS	2
F17	1/2	-	-	NA	-	-	NA	2	NS	-	NS	NS	NS
F18	1/1	*Statu quo*[4]	*Statu quo*	-	Improved	Improved	NA	2	1	2	NS	NS	2

1: ADG = Average Daily Gain, 2: FCR = Feed Conversion Ratio, 3: DDDvet = Defined Daily Dose for animals of antimicrobials. There was no room for improvement (NRI) when no antimicrobials were administered prior to the intervention, 4: Definition of improved, statu quo, deteriorated: see Table 2, 5: "-" = Indicator was not considered to assess tailor-made health plan effectiveness because its evolution was not biologically linked to the targeted health disorder evolution. Methods based on an indicator that was not considered were not used. That is why "-" can be indicated in the results section of the method C, 6: NA = Not Available. Indicators were selected to assess effectiveness but observations could not be performed during visits or data could not be provided by farmers and/or veterinarians, 7: NRI = No Room for Improvement: see Table 2, 8: NS = No scoring since indicators were not avaible or presented no room for improvement at the first visit

The scores of effectiveness differed widely between methods A, B, C, D, E and F:

- The highest proportions of scores 2 were obtained for the veterinarians' opinion (A), the available-indicator method (F) and the clinical observation method (B) (8/14, 7/12 and 4/9, respectively).
- The lowest proportions of scores 2 were obtained for the all-indicator (E), the technical performance (C) and antimicrobial use (D) methods (0/4, 1/6, and 1/7, respectively).

The level of inter-method agreement differed:

- The results of the clinical observation (B) and the available-indicator (F) methods matched the most frequently with those of the veterinarians' opinion (A) (7 times out of 9, 8 times out of 12, respectively). When discrepant, scores obtained with veterinarians' opinions (A) were either higher (once with method B, twice with method F) or lower (once with method B, twice with method F).
- Clinical observation method (B) and the method combining all available indicators (F) matched seven times out of nine. When discrepant, scores obtained with the clinical observation method (B) were lower than with the available–indicator method (F).
- Technical performance (C) and antimicrobial use (D) methods were the two methods whose results were least consistent with those of the veterinarians' opinion (A) (2 times out of 6, 4 times out of 7, respectively). When discrepant, scores obtained with veterinarians' opinions (A) were higher.

Figure 5 describes the results of the effectiveness assessment based on compliance for $TMHP_{prev}$ (G). Out of the 17 $TMHP_{prev}$, 11 were effective, three had an intermediate effectiveness and three were ineffective.

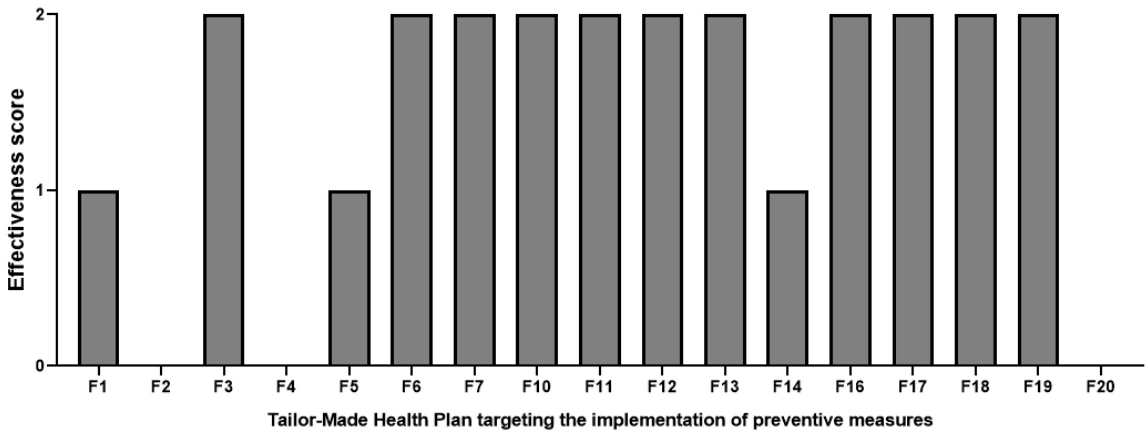

Figure 5 - Assessment of tailor-made health plans with method G based on compliance assessment (Score 2= effective; 1= intermediate; 0= ineffective) for 17 Tailor-Made Health Plans targeting the implementation of preventive measures)

Discussion

In this study, we aimed at assessing the effectiveness of tailor-made health plans designed in a variety of situations following a systematic audit on biosecurity and herd health. Farms were recruited according to their diversity of health statuses and management practices. Resource-based indicator (compliance) and outcome-based indicators (clinical observations, technical performances, and antimicrobial use) were used in this purpose. Seven methods were used and compared to identify key points for the development of future assessments of the effectiveness of health plans in farms. The observations performed at visit 1 were considered to be the control of the monitored farms. It was not feasible to have a control group with on-farm conditions where farmers do not implement any new practices. Furthermore, developing a tailor-made approach, we considered that the situation of each farm is unique and can only be compared to itself.

The compliance with plans was good: almost all of the farmers in this study implemented at least one recommendation (only two out of 20 did not), and on average more than 50% of the recommendations were implemented in each plan. Compliance was systematically considered as a criterion to evaluate the effectiveness of two types of plans. It was the only indicator for prevention plans not targeting any specific health disorder, and the first indicator for plans targeting a health disorder, before assessing outcome-based indicators. For prevention plans, outcome-based indicators could not be implemented due to the type of biosecurity measures recommended. Indeed, the recommended preventive measures mainly concerned the prevention of the introduction of pathogens into the farm (perimeter fence, hygiene lock). To evidence the effectiveness of external biosecurity, farms must be exposed to the risk of pathogen introduction. However, these risks were low in our cohort (closed housing facilities, absence of epizootics during the study, advisors and farmers trained in biosecurity). That is why compliance was the only indicator used to assess the effectiveness of prevention plans. Based on compliance, the majority of prevention plans not targeting any specific health disorder were considered effective. The implementation of preventive measures could be motivated by farmers' risk aversion (Renault et al., 2021), farmers' confidence in their ability to implement new management practices in their daily work (Jones et al., 2016), or the need to comply with French legislation which has been strengthened since the spread of African Swine Fever in Europe (République Française, 2018). Using compliance as a “marker of success” was suggested by Tremetsberger & Winckler (2015) and used in other studies on tailor-made health plans in pig (Collineau et al., 2017) or dairy farms (Green et al., 2007; Duval et al., 2018; Sjöström et al., 2019). Here, we proposed to use compliance as the first indicator of the effectiveness of health plans, then to add outcome-based indicators to the assessment when it is assumed to be relevant. In our cohort, we used this method for plans targeting a specific health disorder present in farms. In that case, we assumed that evidencing a change in indicator can be a useful step to assess effectiveness (even if causation and association cannot be proven in such a study design). On the contrary, in case of the improvement of an outcome-based indicator without implementation of any measures, the observed improvement cannot be attributed to the effectiveness of the health plan. This situation was observed in two farms where outcome-based indicators improved in absence of the implementation of recommended measures. This would have led to erroneous conclusions, if compliance had not been the first criterion considered to assess effectiveness.

Both types of plans included a low number of prioritized recommendations, which was much lower than the number of biosecurity measures not implemented according to the audit. We assume that selecting and prioritizing recommendations could have enhanced compliance. This could have allowed farmers to more easily focus on a specific target to improve. If a larger number of recommendations had been formulated, farmers may have neglected some of them. In a context where economic and time budgets are limited for farmers, some recommendations may not have been implemented due to a lack of money or time (Alarcon et al., 2014). Nonetheless, tailor-made health plans formulated in dairy farms in Germany and Sweden included a median number of recommendations higher than in our study *(i.e.*, 7 in Germany; 15 in Sweden), but their median compliance rate of 67% was similar (Sjöström et al., 2019). To explain the high compliance rates despite the high number of recommendations, Sjölström et al. (2019) argued that herd health planning was probably regularly included in a monitoring system for Swedish dairy farmers. Thus, a large number of recommendations is not necessarily a barrier to compliance but requires that the veterinarian knows well the farmers with whom he works and their motivation, to adapt their advices and taking into account the likelihood of implementing the recommendations.

Compliance with plans targeting a health disorder was better than with prevention plans not targeting a specific health disorder. Other reasons than prioritizing recommendations could explain this difference. Farmers most often cited a lack of willingness as a reason for not implementing all the recommended measures of a prevention plan. This reason was more frequently cited than the economic cost of recommendations, which is known to be a barrier to compliance (Garforth et al., 2013; Alarcon et al., 2014). We assume that farmers perceived less potential benefit to preventive measures in the absence of a health disorder. For example, two pig farmers in this study who reared their pigs in closed housing facilities did not implement a perimeter fence due to a lack of willingness, despite the recommendations of the prevention plans. It is likely that these farmers did not perceive any benefits due to the low risk of disease introduction by wild boars (closed housing facilities) and the high cost of perimenter fences. It is known that the perception of benefits can enhance compliance in the context of a disease risk management

(Garforth et al., 2013; Ritter et al., 2017; Svensson et al., 2019; Moya et al., 2020; Delpont et al., 2021). One way to improve the perception of benefits is to communicate with farmers about evidence-based benefits (Valeeva et al., 2011; Renault et al., 2021). Monitoring outcome-based indicators to assess the effectiveness of plans can contribute to substantiate evidence-based benefits.

In this study, we aimed to describe the evolution of health disorder with several outcome-based indicators related to the targeted disorder. Clinical observations are specific indicators of a health disorder. In our cohort, two-thirds of the plans could be assessed with these indicators. When plans could be assessed, clinical indicators improved about half of times. Three reasons explained why one-third of the plans could not be assessed with clinical observations. First, clinical observations could not always be performed at the time of the visit. The protocol dictated the timing of the visits, so that not all physiological stages could be observed, due for example to later farrowing than expected. Secondly, clinical observations could not be relevant to the targeted health disorder. Outcome-based indicators were selected *a priori* based on i) their ability to assess a change in health disorder with the implementation of a health plan and ii) their specific association with the main infectious diseases likely to be present in the pig farms of the study area. In particular, respiratory and digestive disorders were the most common disorders in the study area. Therefore, the outcome-based indicators selected *a priori* did not allow to monitor other health disorders. For example, a nervous disorder was observed in one farm and could thus not be monitored wih the clinical indicators selected *a priori*. Thirdly, there was no clinical signs at the first visit. Therefore, we concluded that there was no room for improvement, even though veterinarians had previously observed the health disorder. We could have observed animals before or after clinical expressions of the disorders. For all these reasons, we recommend that the type of clinical indicators and their monitoring modalities (duration, frequency of observations) be selected after the first farm visit, depending on the health disorder targeted by the plan.

Technical performances and antimicrobial use can provide additional evidence-based benefits of a plan. However, these indicators are non-specific as other factors besides the targeted disorder can induce their variations. In our cohort, these indicators could not be assessed for more than half of the plans because they were not available. When available, these indicators improved for less than a quarter of times. The two main difficulties in using these indicators were data availability and the choice of the period to monitor them. Technical performances were not systematically monitored by all farmers, and the purchase records of antimicrobial were not always provided by veterinarians. The difficulty of accessing antimicrobial use data in pig farms had already been described in another intervention study in Belgium, where tailor-made health plans were also formulated (Postma et al., 2017). The usual follow-up period indicated in the technical documents and antimicrobial purchase records in our cohort was one year. This time window may not be suitable for all indicators and all health disorders. For example, it was probably too long to observe a decrease in antimicrobial use attributable to plan effectiveness in our cohort. To overcome this limitation, we recommend to adapt the studied time window of each monitored indicator to the targeted health disorder.

The opinions of veterinarians on the effectiveness of health plans targeting a specific health disorder were recorded for each plan, regardless of the assessed indicators. We aimed to compare the opinions of veterinarians with five methods assessing effectiveness to discuss potential reasons for discrepancies. The majority of veterinarians involved in this study had been collaborating with the recruited farmers for several years. They were familiar with these farmers and the health context of the farm beforehand. It is assumed that the length of the relationships and the knowledge of the farms allowed the veterinarians to access different types of information to conclude on the effectiveness of their health plans. Indeed, Bard et al. (2019) observed through qualitative interviews with pig farmers and veterinarians, that advisors could access certain information or not depending on the quality of their relationship with the farmer. Furthermore, the clinical reasoning of veterinarians was based on holistic information gathering (May, 2013; Vinten et al., 2016). It is assumed that some outcome-based indicators are included among all the collected information.

The effectiveness of a plan targeting a health disorder could differ according to the method used. Therefore, the outcome-based indicators captured *a priori* complementary information. Discrepancies in effectiveness could be explained by differences between indicators in specificity or in studied time window. Veterinarians' opinions mostly matched with clinical observations. The few discrepancies between these two methods suggest that the information captured by clinical observations could have sometimes a limited temporal validity or be incomplete. The temporal validity of observed clinical information is limited since clinical severity could differ depending on the observation time. Incomplete information may be due to the fact that a single outcome-based indicator does not provide enough information to precisely describe a health disorder in farm (Zimmerman et al., 2019). Combinations of indicators were thus used to have a more holistic health description. The combinations were complex to use. One method required the combination of all outcome-based indicators and concluded to an effective plan, only if an improvement in at least one indicator was observed without any deterioration elsewhere. The individual limits of each indicator (missing data, low specificity, inadequate studied time window) explain why this method was rarely applicable and systematically resulted in ineffective plans. Another method, which only combined the available indicators, could be used (by construction) more frequently than all other methods, except for the method based on the veterinarians' opinion. Some discrepancies in results compared to veterinarians' opinion could be explained by the lack of specificity or limited temporal validity of the available indicators. Our results suggest that the relevance of combining indicators to assess the evolution of a health disorder depends i) on the availability of data in farm, ii) on the specificity of the indicators, and iii) on the relevance of the targeted time window to monitor indicators. The absence of data for clinical indicators, technical performances, and antimicrobial use could have been avoided by selecting indicators adapted to each farm in collaboration with farmers and veterinarians (Vaarst, 2011; Tremetsberger et al., 2015; Duval et al., 2016). This approach allows to assess the evolution of a health disorder within a farm but not to compare or to synthetize results in several farms, since the indicators used would *a priori* differ across farms.

Careful consideration is required to identify how to choose indicators and how to combine them according to specific health disorders. Missing data and inadequate studied time window observed in this study, suggest that indicators and their monitoring modalities (length, frequence) should be selected after an initial visit of the farm, in collaboration with farmers and veterinarians (Duval et al., 2016; Tremetsberger & Winckler, 2015; Vaarst, 2011). This will allow a more precise adaptation of health monitoring in each farm and a more accurate description of the evolution of health disorders. Moreover, other types of outcome-based indicators, in addition to those used in this study, could be considered to provide a more comprehensive description of health. For instance, observations in slaughterhouses could be performed since they are useful for some health disorders (Scollo et al., 2022). Indicator to assess the effectiveness of the use of antimicrobials could be considered, such as bacterial load or recovery rate after treatment. A multi-criteria method, as already used by (Martín et al., 2017) to assess the welfare of finishing pigs, would be of interest to holistically assess the evolution of a health disorder.

To conclude, tailor-made health plans were designed in a variety of situations following a systematic audit on biosecurity and herd health. Two types of tailor-made health plans could be formulated to each farm : a plan to improve prevention not targeting a specific health disorder, and a plan to improve one targeted specific health disorder. To assess the effectiveness of prevention plans, only the compliance of recommended measures was assumed to be relevant. Most of prevention plans were effective since recommended measures were implemented. To assess the effectiveness of plans targeting a health disorder to improve, outcome-based indicators were used in addition to compliance. The effectiveness assessment with a combination of indicators was complex. Three key points were identified from these results for future assessments of the effectiveness of tailor-made health plans. Firstly, compliance should be the first indicator of assessment. Seconldy, outcome-based indicators and their monitoring modalities (length, frequence) should be adapted to each farm and to the targeted health disorder. Thirdly, indicators should be combined to have a holistic and precise description of a health disorder. Further research is needed to identify how to select indicators to combine and how to combine them, according to health disorders.

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Conflict of interest disclosure

The authors declare that they comply with the PCI rule of having no financial conflicts of interest in relation to the content of the article.

Data availability

Data are available online: https://doi.org/10.5281/zenodo.7788872 (Levallois et al. 2023).

References

Alarcón LV, Allepuz A, Mateu E. 2021. Biosecurity in pig farms: a review. Porcine Health Management 7:5. https://doi.org/10.1186/s40813-020-00181-z

Alarcon P, Wieland B, Mateus ALP, Dewberry C. 2014. Pig farmers' perceptions, attitudes, influences and management of information in the decision-making process for disease control. Preventive Veterinary Medicine 116:223–242. https://doi.org/10.1016/j.prevetmed.2013.08.004

Bard AM, Main D, Roe E, Haase A, Whay HR, Reyher KK. 2019. To change or not to change? Veterinarian and farmer perceptions of relational factors influencing the enactment of veterinary advice on dairy farms in the United Kingdom. Journal of Dairy Science 102:10379–10394. https://doi.org/10.3168/jds.2019-16364

Blanco-Penedo I, Sjöström K, Jones P, Krieger M, Duval J, van Soest F, Sundrum A, Emanuelson U. 2019. Structural characteristics of organic dairy farms in four European countries and their association with the implementation of animal health plans. Agricultural Systems 173:244–253. https://doi.org/10.1016/j.agsy.2019.03.008

Chincarini M. 2023. Evaluating tailor-made health plans in pig farms: a multiple complementary indicators approach. Peer Community in Animal Science, 100195. https://doi.org/10.24072/pci.animsci.100195

Clark B, Panzone LA, Stewart GB, Kyriazakis I, Niemi JK, Latvala T, Tranter R, Jones P, Frewer LJ. 2019. Consumer attitudes towards production diseases in intensive production systems. PLOS ONE 14:e0210432. https://doi.org/10.1371/journal.pone.021043

Collineau L, Rojo-Gimeno C, Léger A, Backhans A, Loesken S, Nielsen EO, Postma M, Emanuelson U, Beilage E grosse, Sjölund M, Wauters E, Stärk KDC, Dewulf J, Belloc C, Krebs S. 2017. Herd-specific interventions to reduce antimicrobial usage in pig production without jeopardising technical and economic performance. Preventive Veterinary Medicine 144:167–178. https://doi.org/10.1016/j.prevetmed.2017.05.023

Delpont M, Racicot M, Durivage A, Fornili L, Guerin J, Vaillancourt J, Paul MC. 2021. Determinants of biosecurity practices in French duck farms after a H5N8 Highly Pathogenic Avian Influenza epidemic: The effect of farmer knowledge, attitudes and personality traits. Transboundary and Emerging Diseases 68:51–61. https://doi.org/10.1111/tbed.13462

Dixon LK, Sun H, Roberts H. 2019. African swine fever. Antiviral Research 165:34–41. https://doi.org/10.1016/j.antiviral.2019.02.018

Duval JE, Bareille N, Madouasse A, de Joybert M, Sjöström K, Emanuelson U, Bonnet-Beaugrand F, Fourichon C. 2018. Evaluation of the impact of a Herd Health and Production Management programme in organic dairy cattle farms: a process evaluation approach. Animal 12:1475–1483. https://doi.org/10.1017/S1751731117002841

Duval JE, Fourichon C, Madouasse A, Sjöström K, Emanuelson U, Bareille N. 2016. A participatory approach to design monitoring indicators of production diseases in organic dairy farms. Preventive Veterinary Medicine 128:12–22. https://doi.org/10.1016/j.prevetmed.2016.04.001

European Medicines Agency. 2015. Principles on assignment of defined daily dose for animals (DDDvet) and defined course dose for animals (DCDvet). Available at: http://www.ema.europa.eu/docs/en_GB/document_library/Scientific_guideline/2015/06/WC500188890.pdf (accessed on November, 4th 2015).

FAO. 2015.The 3-Zone Biosecurity Model. Available at http://www.fao.org/indonesia/programmes-and-projects/ectad-indonesia/successful-practices/en/ (accessed December 23, 2022).

Fraser D, Weary DM, Pajor EA, Milligan BN. 1997. A Scientific Conception of Animal Welfare that Reflects Ethical Concerns. Animal welfare 6:187–205.

Garforth CJ. 2015. Livestock Keepers' Reasons for Doing and Not Doing Things Which Governments, Vets and Scientists Would Like Them to Do. Zoonoses and Public Health 62:29–38. https://doi.org/10.1111/zph.12189

Garforth CJ, Bailey AP, Tranter RB. 2013. Farmers' attitudes to disease risk management in England: A comparative analysis of sheep and pig farmers. Preventive Veterinary Medicine 110:456–466. https://doi.org/10.1016/j.prevetmed.2013.02.018

Green MJ, Leach KA, Breen JE, Green LE, Bradley AJ. 2007. National intervention study of mastitis control in dairy herds in England and Wales. Veterinary Record 160:287–293. https://doi.org/10.1136/vr.160.9.287

Holtkamp DJ, Kliebenstein JB, Neumann EJ, Zimmerman JJ, Rotto HF, Yoder TK, Wang C, Yeske PE, Mowrer CL, Haley CA. 2013. Assessment of the economic impact of porcine reproductive and respiratory syndrome virus on United States pork producers. Journal of Swine Health and Production 21:72–84.

Huber N, Andraud M, Sassu EL, Prigge C, Zoche-Golob V, Käsbohrer A, D'Angelantonio D, Viltrop A, Żmudzki J, Jones H, Smith RP, Tobias T, Burow E. 2022. What is a biosecurity measure? A definition proposal for animal production and linked processing operations. One Health 15:100433. https://doi.org/10.1016/j.onehlt.2022.100433

Ivemeyer S, Smolders G, Brinkmann J, Gratzer E, Hansen B, Henriksen BIF, Huber J, Leeb C, March S, Mejdell C, Nicholas P, Roderick S, Stöger E, Vaarst M, Whistance LK, Winckler C, Walkenhorst M. 2012. Impact of animal health and welfare planning on medicine use, herd health and production in European organic dairy farms. Livestock Science 145:63–72. https://doi.org/10.1016/j.livsci.2011.12.023

Jones PJ, Sok J, Tranter RB, Blanco-Penedo I, Fall N, Fourichon C, Hogeveen H, Krieger MC, Sundrum A. 2016. Assessing, and understanding, European organic dairy farmers' intentions to improve herd health. Preventive Veterinary Medicine 133:84–96. https://doi.org/10.1016/j.prevetmed.2016.08.005

Kristensen E, Jakobsen EB. 2011. Challenging the myth of the irrational dairy farmer; understanding decision-making related to herd health. New Zealand Veterinary Journal 59:1–7. https://doi.org/10.1080/00480169.2011.547162

Lam T, Jansen J, van den Borne B, Renes R, Hogeveen H. 2011. What veterinarians need to know about communication to optimise their role as advisors on udder health in dairy herds. New Zealand Veterinary Journal 59:8–15. https://doi.org/10.1080/00480169.2011.547163

Levallois P, Leblanc-Maridor M, Scollo A, Ferrari P, Belloc C, & Fourichon C. 2023. Raw_data_Combining several indicators to assess the effectiveness of tailor-made health plans in pig farms [Data set]. Zenodo. https://doi.org/10.5281/zenodo.7788872

Levallois P, Leblanc-Maridor M, Belloc C, Fourichon C. 2022. From biosecurity audit to tailor-made recommendations in pig farms: how to prioritize action points? 73rd EAAP meeting, Porto.

Lun Z-R, Wang Q-P, Chen X-G, Li A-X, Zhu X-Q. 2007. Streptococcus suis: an emerging zoonotic pathogen. The Lancet Infectious Diseases 7:201–209. https://doi.org/10.1016/S1473-3099(07)70001-4

Maes D, Sibila M, Kuhnert P, Segalés J, Haesebrouck F, Pieters M. 2018. Update on Mycoplasma hyopneumoniae infections in pigs: Knowledge gaps for improved disease control. Transboundary and Emerging Diseases 65:110–124. https://doi.org/10.1111/tbed.12677

Martín P, Czycholl I, Buxadé C, Krieter J. 2017. Validation of a multi-criteria evaluation model for animal welfare. Animal 11:650–660. https://doi.org/10.1017/S1751731116001737

May SA. 2013. Clinical Reasoning and Case-Based Decision Making: The Fundamental Challenge to Veterinary Educators. J Vet Med Educ 40:200–209. https://doi.org/10.3138/jvme.0113-008R

Moya S, Tirado F, Espluga J, Ciaravino G, Armengol R, Diéguez J, Yus E, Benavides B, Casal J, Allepuz A. 2020. Dairy farmers decision-making to implement biosecurity measures. Transboundary and Emerging Diseases 67:698–710. https://doi.org/10.1111/tbed.13387

Nathues H, Alarcon P, Rushton J, Jolie R, Fiebig K, Jimenez M, Geurts V, Nathues C. 2017. Cost of porcine reproductive and respiratory syndrome virus at individual farm level – An economic disease model. Preventive Veterinary Medicine 142:16–29. https://doi.org/10.1016/j.prevetmed.2017.04.006

OIE. 2021. Introduction to the recommendations for animal welfare. In: Terrestrail animal health code. 800.

Postma M, Vanderhaeghen W, Sarrazin S, Maes D, Dewulf J. 2017. Reducing Antimicrobial Usage in Pig Production without Jeopardizing Production Parameters. Zoonoses and Public Health 64:63–74. https://doi.org/10.1111/zph.12283

Raasch S, Collineau L, Postma M, Backhans A, Sjölund M, Belloc C, Emanuelson U, Beilage E grosse, Stärk K, Dewulf J, on the behalf of the MINAPIG Consortium. 2020. Effectiveness of alternative measures to reduce antimicrobial usage in pig production in four European countries. Porcine Health Management 6:6. https://doi.org/10.1186/s40813-020-0145-6

Racicot M, Venne D, Durivage A, Vaillancourt J-P. 2012. Evaluation of the relationship between personality traits, experience, education and biosecurity compliance on poultry farms in Québec, Canada. Preventive Veterinary Medicine 103:201–207. https://doi.org/10.1016/j.prevetmed.2011.08.011

Renault V, Damiaans B, Humblet M, Jiménez Ruiz S, García Bocanegra I, Brennan ML, Casal J, Petit E, Pieper L, Simoneit C, Tourette I, Wuyckhuise L, Sarrazin S, Dewulf J, Saegerman C. 2021. Cattle farmers' perception of biosecurity measures and the main predictors of behaviour change: The first European-wide pilot study. Transboundary and Emerging Diseases 68:3305–3319. https://doi.org/10.1111/tbed.13935

République Française. 2017. Arrêté du 27 juillet 2017 fixant les conditions de production communes relatives à la production en label rouge "porc" - Annexe.

République Française. 2018. Arrêté du 16 octobre 2018 relatif aux mesures de biosécurité applicables dans les exploitations détenant des suidés dans le cadre de la prévention de la peste porcine africaine et des autres dangers sanitaires réglementés.

Ritter C, Jansen J, Roche S, Kelton DF, Adams CL, Orsel K, Erskine RJ, Benedictus G, Lam TJGM, Barkema HW. 2017. Invited review: Determinants of farmers' adoption of management-based strategies for infectious disease prevention and control. Journal of Dairy Science 100:3329–3347. https://doi.org/10.3168/jds.2016-11977

Rojo-Gimeno C, Postma M, Dewulf J, Hogeveen H, Lauwers L, Wauters E. 2016. Farm-economic analysis of reducing antimicrobial use whilst adopting improved management strategies on farrow-to-finish pig farms. Preventive Veterinary Medicine 129:74–87. https://doi.org/10.1016/j.prevetmed.2016.05.001

Roskam JL, Lansink AGJMO, Saatkamp HW. 2019. The technical and economic impact of veterinary interventions aimed at reducing antimicrobial use on broiler farms. Poultry Science 98:6644–6658. https://doi.org/10.3382/ps/pez517

Scollo A, Levallois P, Fourichon C, Motta A, Mannelli A, Lombardo F, Ferrari P. 2022. Monitoring Means and Results of Biosecurity in Pig Fattening Farms: Systematic Assessment of Measures in Place and Exploration of Biomarkers of Interest. Animals 12:2655. https://doi.org/10.3390/ani12192655

Silva GS, Corbellini LG, Linhares DLC, Baker KL, Holtkamp DJ. 2018. Development and validation of a scoring system to assess the relative vulnerability of swine breeding herds to the introduction of PRRS virus. Preventive Veterinary Medicine 160:116–122. https://doi.org/10.1016/j.prevetmed.2018.10.004

Simon-Grifé M, Martín-Valls GE, Vilar MJ, García-Bocanegra I, Martín M, Mateu E, Casal J. 2013. Biosecurity practices in Spanish pig herds: Perceptions of farmers and veterinarians of the most important biosecurity measures. Preventive Veterinary Medicine 110:223–231. https://doi.org/10.1016/j.prevetmed.2012.11.028

Sjöström K, Sternberg-Lewerin S, Blanco-Penedo I, Duval JE, Krieger M, Emanuelson U, Fall N. 2019. Effects of a participatory approach, with systematic impact matrix analysis in herd health planning in organic dairy cattle herds. Animal 13:358–366. https://doi.org/10.1017/S1751731118002008

Svensson C, Lind N, Reyher KK, Bard AM, Emanuelson U. 2019. Trust, feasibility, and priorities influence Swedish dairy farmers' adherence and nonadherence to veterinary advice. Journal of Dairy Science 102:10360–10368. https://doi.org/10.3168/jds.2019-16470

Tremetsberger L, Leeb C, Winckler C. 2015. Animal health and welfare planning improves udder health and cleanliness but not leg health in Austrian dairy herds. Journal of Dairy Science 98:6801–6811. https://doi.org/10.3168/jds.2014-9084

Tremetsberger L, Winckler C. 2015. Effectiveness of animal health and welfare planning in dairy herds: a review. Animal Welfare 24:55–67. https://doi.org/10.7120/09627286.24.1.055

Vaarst M, Winckler C, Roderick S, Smolders G, Ivemeyer S, Brinkmann J, Mejdell CM, Whistance LK, Nicholas P, Walkenhorst M, Leeb C, March S, Henriksen BIF, Stöger E, Gratzer E, Hansen B, Huber J. 2011. Animal Health and Welfare Planning in Organic Dairy Cattle Farms. The Open Veterinary Science Journal 5:19–25. https://doi.org/10.2174/1874318801105010019

Valeeva NI, van Asseldonk MAPM, Backus GBC. 2011. Perceived risk and strategy efficacy as motivators of risk management strategy adoption to prevent animal diseases in pig farming. Preventive Veterinary Medicine 102:284–295. https://doi.org/10.1016/j.prevetmed.2011.08.005

Vinten CEK, Cobb KA, Freeman SL, Mossop LH. 2016. An Investigation into the Clinical Reasoning Development of Veterinary Students. Journal of Veterinary Medical Education 43:398–405. https://doi.org/10.3138/jvme.0815-130R1

Zimmerman JJ, Karriker LA, Ramirez A, Schwartz KJ, Stevenson GW, Zhang J. 2019. Diseases of Swine. Wiley Blackwell.

Appendices

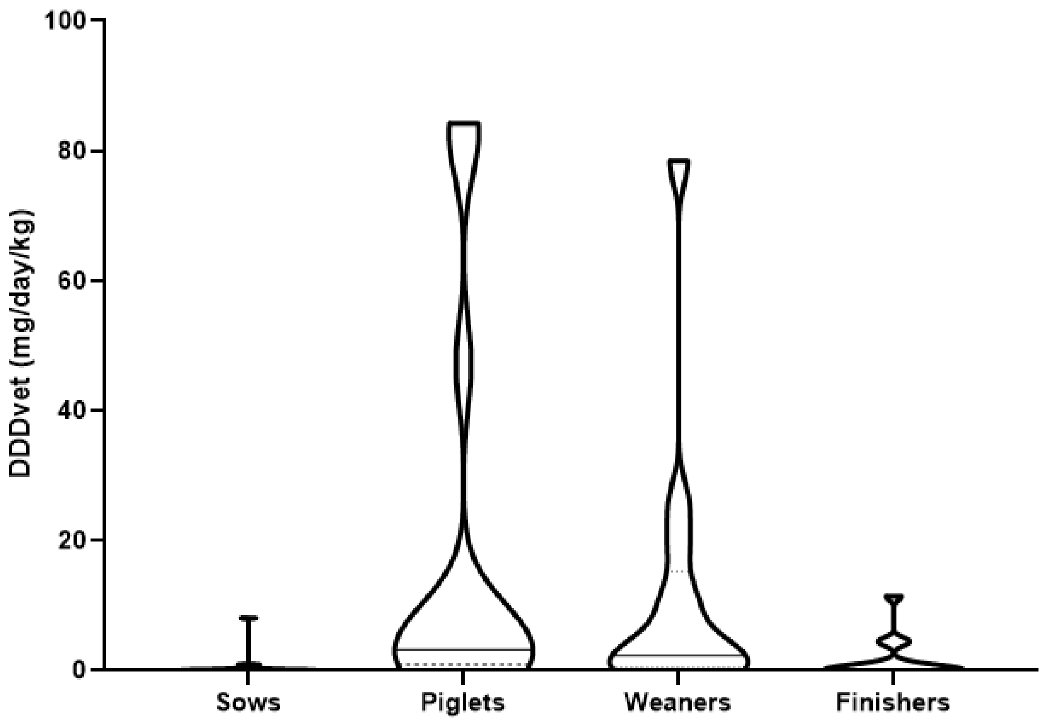


Figure A1 - Distribution of farm Defined Daily Dose for animals (DDDvet) for each group of animals (n=12 farms): sows, suckling piglets, weaners and finishers. Violin plots including medians (plain lines) and first and third quartiles (dotted lines).

Table A1 - Mean and standard-deviation of technical performance indicators in farms the year before the intervention and the on-going year after intervention

	Number of farms with available data	Mean ± standard deviation Before	After
Number of piglets weaned / productive sow / year	15	30.7 ± 3.3	31.5 ± 3.6
ADG[1] wean-to-finish (g/day)	12	718.3 ± 56.8	718.7 ± 62.0
FCR[2] wean-to-finish (kg/kg)	12	2.5 ± 0.3	2.5 ± 0.2
Mortality post-weaning (%)	11	4.0 ± 4.6	3.9 ± 4.0
Mortality fattening (%)	10	3.3 ± 1.9	3.6 + 1.2

1: ADG = Average Daily Gain, 2: FCR = Feed Conversion Ratio

Table A2: Description of identified health disorders in farms at visit 1 and of the evolutions of indicators related to health disorders

Farm	Health disorder	Animals concerned	Indicator *Visit 1 – Visit 3*						
			Cough *Number / 2 minutes / 100 animals*	**Sneeze** *Number / 2 minutes / 100 animals*	**Faeces score** *% scores 2 + 3*	**ADG[1]** *g/day*	**FCR[2]** *kg/kg*	**DDDvet[3]** **mg/day/kg/1000 animals**	**Missing indicator[4]**
F1	Cough and sneeze	Post-weaning piglets	56.0 - 0.0	14.0 - 1.4	/[5]	NA[6]	NA	/	/
F3	Cough and sneeze	Post-weaning piglets	13.8 - 2.7	22.3 - 2.2	/	766 - 746	2.24 - 2.29	/	/
F4	Ileitis	Fattening pigs	/	/	0 - 0	NA	NA	4.5 – 17.3	/
F6	Diarrhoea	Suckling piglets	/	/	50 - 0	/	/	2.7 – 3.3	/
F8	Diarrhoea	Suckling piglets	/	/	0 – 0	/	/	81.0 – 168.5	/
F9	Neurologic and locomotor disorders related to *Streptococcus suis*	Post-weaning piglets	/	/	/	731 - 714	2.44 - 2.39	5.3 – 4.0	Clinical observation of locomotor and neurologic disorders
F10a	Porcine Respiratory and Reproductive Syndrom	Fattening pigs	1.0 – 0	19.4 – 6.1	/	NA	NA	/	/
		Gestating sows	/	/	/	/	/	/	Numbers of born dead, abortion
F10b	Diarrhoea	Suckling piglets	/	/	100 - 0	/	/	0.4 – 0.9	/
F11	Ileitis	Fattening pigs	/	/	0 -0	NA	NA	NA	/
F14	Tail biting	Post-weaning piglets and fattening pigs	/	/	/	NA	NA	/	Clinical observation of the severity of tail biting
F15	Cough and sneeze	Post-weaning piglets	10.6 - 0.3	3.2 - 3.9	/	742 - 718	2.25 – 2.28	3.2 – 3.0	/
F16	Diarrhoea	Post-weaning piglets	/	/	12.5 - 77.8	733 - 766	2.18 - 2.30	NA	/
F17	Diarrhoea	Suckling piglets	/	/	NA	/	/	NA	/
F18	Cough	Fattening pigs	35.6 - 12.9	6.2 - 6.4	/	710 - 721	2.76 - 2.61	NA	/

1: ADG = Average Daily Gain, 2: FCR = Feed Conversion Ratio, 3: DDDvet = Defined Daily Dose for animals of antimicrobials., 4: Indicator that were not monitored in this study could be required to describe the identified health disorders, 5 : Indicator not selected since its evolution could not be biologically explained by the health disorder evolution. Regarding DDDvet, their values were only considered to describe the evolution of health disorders when antimicrobials were administrated to animals for the identified health disorders before the intervention, 6: NA = Not assessed since animals could not be observed at the time of the visit or because data could not be provided by farmers and/or veterinarians

Biosecurity Risk Analysis Tool (BEAT) - Pig farms - Healthy Livestock

HealthyLivestock

Introduction

This draft Risk Analysis Tool is based on literature review of risks for major French and Italian pig diseases. The structure of the audit anticipates on the format of the health plans to be worked out, which will according to the description based on the FAO risk zoning (red-orange-green).

Farm characteristics

Name company/farmer: .....

Adress, residence: ....

nr. pig houses/nr. pig per house: ......

Guideline to veterinarian and pig farmer

Step 1 Define on-farm risk zones

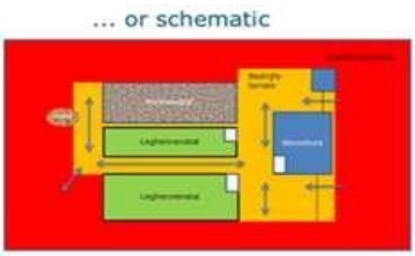
Download a Google Earth map of the farm location and color the risk zones (red-orange-green)
Make a schematic drawing of the farm location and color the risk zones, and identify the buildings, stables, storage sites, pathways et cetera.

Example

Green zone = pig houses and entree rooms: clean, strictly isolated, restricted access

Orange zone = paved surfaces and functional farm areas: biosecurity measures to reduce contamination with foreign manure to medium/low risk

Red zone = external areas (unpaved roads, ditches, pasture, etc.: high risks, farmers acting opportunities)



Step 2 Go through the risk analysis tool
Answer the questions belonging to the different zones and transition lines between zones (see tabs) and score the risk. The sections 'TRANSITION ORANGE-GREEN
ZONE' and 'GREEN ZONE' should be filled out for each pig house on the farm

Step 3 Interpretation
In the tab "Overall scores" at the end of the file, allow to show an overview of scores per zone. Veterinarian and farmer: Analyze together the automatically
generated scores and discuss: where are opportunities for improvements?

Step 4 Health plan

Make an action plan with SMART formulated preventative actions for strenghtening of on-farm biosecurity

NB: * in the following pages refers to the following caption : write NA for non applicable constitions

CRPA INRAE Oniris VETERINARY MEDICINE, FOOD SCIENCE AND ENGINEERING NATIONAL COLLEGE

The EU part of the HealthyLivestock project is funded by the EU Horizon 2020 research and innovation program under grant agreement number 773436

BEAT table 1: Biosecurity in the red zone (public zone)

	Risk Factors	Objective	Conditions	Means in place to reach the objective	Score[a]: 1 no risk or under control / 0,75 low risk / 0,25moderate risk / 0 high risk	Major improvement needed	Is it critical inthis farm (yes/no)
1	Neighbourhood activities	Awareness of at-risk situation due to neighbourhood	Pig density in the area - average pig density at municipality level >300 pigs/km²: no score 1; yes score 0				
2			Distance to other pig farms: >3km score 1; 1 to 3 km score0.75; 0.5 to 1 km score 0.25, 0.5km score 0				
3			Abattoir close to the farm - distance: >3km score 1; 1 to 3 kmscore 0.75; 0.5 to 1 km score 0.25, 0.5km score 0				
4			Road with frequent pig transport close to the farm - distance: >3km score 1; 1 to 3 km score 0.75; 0.5 to 1 km score 0.25, 0.5km score 0				
5			Wild boars spotted in the neighborhood within a radius of 10km: no score 1; yes score 0				
6	External vehicles	To maintain in the public zone vehicles and persons with no necessary access to theprofessional zone	Parking for staff and visitors in the public zone: yes score 1; noscore 0				
7			Separate access ways for rendering plant trucks: yes score 1;no score 0				
8			Separate access for feed supply: yes score 1; no score 0				
9			Separate access for manure elimination: yes score 1; no score0				
10	Dead animals	To reduce load of pathogens associated with elimination of dead animals	Storage of cadavers in the public zone: yes score 1; no score0				
11			Frequency of elimination of cadavers from the farm adapted tothe storage: yes score 1; no score 0				
12			Cleaning and disinfection of the storage equipment after every cadaver collection: yes score 1; no score 0				

[a]write NA in column F if not applicable

(higher score is less risk) *(max= 12 if all points applicable. Otherwise max score is calculated in F18)*

OVERALL BIOSECURITY SCORE RED ZONE:	0
Maximum possible score:	0
Percentage of maximum score:	**#DIV/0!**

BEAT table 2: Biosecurity in the transition between the red zone (public zone) and the orange zone (professional zone)

	Risk Factors	Objective	Conditions	Means in place to reach the objective	Score[a]: 1 no risk or under control / 0,75 low risk / 0,25 moderate risk / 0 high risk	Major improvement needed	Is it critical in this farm (yes/no)
1	Contamination from truck and visitors	To prevent contamination of the professional zone by trucks and visitors	Arrival sign: yes score 1; no score 0				
2			Access exclusively for pig transport vehicles: yes score 1; no score 0				
3			Access limited to in-advance-thoroughly-cleaned-and-disinfected transport vehicles: yes score 1; no score 0				
4			Cleaning and disinfection of tires before entering the orange zone (all transports): yes score 1; no score 0				
5			Truck platform equipped with fixed or manual equipment for wheels, lateral and undersides vehicles disinfection: yes score 1; no score 0				
6			Presence of a platform to house temporarily and load pigs for slaughter: yes score 1; no score 0				
7			Cleaning and disinfection of the platform after each delivery: yes score 1; no score 0				
8	Contamination by wildlife	To prevent contamination of the professional zone by wildlife	Delimitation of the professional zone to prevent access of wild animals (e.g. perimetral fence against wild boars): yes score 1; no score 0				
9	Contamination by staff in charge of elimination of dead animals	To prevent contamination by staff in charge of elimination of dead animals in the public zone	Specific clothes and shoes for staff to eliminate dead animals in the public zone: yes score 1; no score 0				
10			Cleaning and disinfection of the material used to transfer dead animals in the public zone: yes score 1; no score 0				
11			Cleaning and disinfection of the shoes after transfer of dead animals in the public zone: yes score 1; no score 0				
12			Hand washing after transfer of dead animals in the public zone: yes score 1; no score 0				
13	Staff and visitors	To prevent introduction of diseases by staff and visitors entering the farm	Well located hygiene lock with dirty and clean area available: yes score 1; no score 0				
14			Provision of the hygiene lock with company footwear or overshoes: yes score 1; no score 0				
15			Provision of the hygiene lock with company clothes/overalls: yes score 1; no score 0				
16			Provision of the hygiene lock with hand hygiene facilities: yes score 1; no score 0				
17			Provision of the hygiene lock with one or more showers: yes score 1; no score 0				
18			Provision of the hygiene lock with adequate hygiene Standard Operating Procedure for visitors / employees / farmer available: yes score 1; no score 0				
19			Correct use of hygiene lock provisions by farm workers: yes score 1; no score 0				
20			Correct use of hygiene lock provisions by visitors: yes score 1; no score 0				
21	Unnecessary access	To avoid unnecessary access to the professional zone	Clear delimitation of the professional zone: yes score 1; no score 0				
22			No access of the public to the orange zone: no access score 1; possible access score 0				
23			No access of trucks eliminating dead animals: no access score 1; possible score 0				
24			Availability of a visitors' register mentioning a period of at least 12 hours between two pig farm visits: yes score 1; no score 0				

[a]write NA in column F if not applicable

(higher score is less risk) *(max= **24** if all points applicable. Otherwise max score is calculated in F36 = applicable points x 4)*

OVERALL BIOSECURITY SCORE TRANSITION ZONE R-O:	**0**
Maximum score	0
Percentage of maximum score:	**#DIV/0!**

BEAT table 3: Biosecurity in the orange zone (professional zone)

	Risk Factors	Objective	Conditions	Means in place to reach the objective	Score[a]: 1 no risk or under control / 0,75 low risk / 0,25 moderate risk / 0 high risk	Major improvement needed	Is it critical in this farm (yes/no)
1	Contamination by wildlife	To prevent contamination of the professional zone by wildlife	Protocols for control of rodents: protocol + registered treatments score 1; no protocol or no register for treatments score 0				
2			Protocols for control of insects (protocol + registered treatments score 1; no protocol or no register for treatments score 0				
3	Contamination by manure	To prevent contamination by the manure	Manure storage separated from the pig houses: yes score 1; no score 0				
4			Possible contamination from slurry tanks to pig houses during transfer and storage of manure: no score 1; yes score 0				
5	Pathogen persistence	To prevent persistence of pathogens in the professional zone	Stored material providing shelter for rodents and parasites: no score1; yes score 0				
6			Washable surface and flooring combined with high pressure water: yes score 1; no score 0				
7	Contamination by staff storing dead animals	To prevent contamination by staff in charge of storing dead animals in the professional zone	Specific gloves, clothes and shoes for staff to transfer and store dead animals in the professional zone: yes score 1; no score 0				
8			Cleaning and disinfection of the material used to transfer dead animals in the professional zone: yes score 1; no score 0				
9			Cleaning and disinfection of shoes after the transfer of dead animals in the professional zone: yes score 1; no score 0				
10			Hand washing and disinfection after the transfer of dead animals in the professional zone: yes score 1; no score 0				
11			Daily elimination of cadavers from the professional zone: yes score 1; no score 0				
12			Cleaning and disinfection of the storage equipment after every cadaver collection: yes score 1; no score 0				

[a]write NA in column F if not applicable

(higher score is less risk)
calculated in F36 = applicable points)

*(max= **12** if all points applicable. Otherwise max score is*

OVERALL BIOSECURITY SCORE ORANGE ZONE: 0
Maximum score. 0
Percentage of maximum score **#DIV/0!**

BEAT table 4: Biosecurity at the transition between the orange zone (professional zone) and the green zone (livestock zone)

Pig house[1] nr: ....

	Risk Factors	Objective	Conditions	Means in place to reach the objective	Score[a]: 1 no risk or under control / 0,75 low risk / 0,25moderate risk / 0 high risk	Major improvement needed	Is it critical in this farm (yes/no)
1	Pathogens from purchased animals	To prevent pathogen introduction by animals introduced into the herd	Origin of animals: Specific Pathogen Free farms score 1; from a unique farm score 0.75; from more than one known farm score 0.25; from more than one unknown farm score 0				
2			Position of the quarantine in the farm (distance from other pig houses >120 m score 1; from 60 to 120 m score 0.75; from 30 to 60 m score 0.25; <30 m score 0				
3			Conditions of quarantine (duration at least 30 d, daily observation, cleaning and disinfection after each batch): yesscore 1; no score 0				
4	Pathogens from other purchases	To prevent introduction of pathogens by other purchases	Facilities for delivery in the livestock zone: room available tostore temporarely and check materials score 1; no room available score 0				
5			Origin of purchased goods (to be listed and assessed): risk under control score 1; possible introduction of pathogens score 0				
6	Pathogens from shared equipment	To prevent introduction of pathogens by shared equipment entering the farm	Use of equipment shared between farms: no score 1; yes score 0				
7			Presence of a room, disinfectants and a Standard Operating Procedure for disinfection of shared equipment: yes score 1; no score 0				
8	Pathogens from staff or visitors	To prevent introduction of pathogens by staff/visitors	Contacts of staff with other pig farms: no score 1; yes score 0				
9			Entree room available, with clear dirty and clean areas, as hygiene lock at the entrance of the pig houses for farrowing or weaning or quarantine: yes score 1; no score 0				
10			Specific footwear available at the entrance of the pig house: yes score 1; no score 0				
11			Specific clothes/overalls available at the entrance of the pig house: yes score 1; no score 0				
12			Hand hygiene facilities available at the entrance of the pig house: yes score 1; no score 0				
13			Barn hygiene protocol available for visitors / employees / farmer: yes score 1; no score 0				
14			Correct use of provisions at the entrance of the pig house byfarm workers: yes score 1; no score 0				
15			Correct use of entree room at the entrance of the pig house provisions by visitors: yes score 1; no score 0				
16	Unnecessary access to the livestock zone	No unnecessary access to the livestockzone	No unnecessary access of persons: no access score 1; access score 0				
17			No unnecessary of domestic animals: no access score 1; access score 0				
18			Presence of anti-bird nets: yes score 1; no score 0				
19			Presence of anti-insect screens: yes score 1; no score 0				

[a]write NA in column F if not applicable

(higher score is less risk) *(max= 19 if all applicable conditions. Otherwise max score is calculated in F36 = applicable points)*

To be completed for each pig house on the farm

OVERALL BIOSECURITY SCORE TRENSITION ZONE O-G:	**0**
Maximum score	0
Percentage of maximum score:	**#DIV/0!**

BEAT table 5: Biosecurity in the green zone (livestock zone) **Pig house[1] nr: ....**

	Risk factors	Objectives	Conditions	Means in place to reach the objective	Score[a]: 1 no risk or under control / 0,75 low risk / 0,25 moderate risk / 0 high risk	Major improvement needed	Is it critical in this farm (yes/no)
1	Animal contact between age groups	To prevent transmission of pathogens between age groups by animal contacts	Strict separation between housing for different age groups: yes score 1; no score 0				
2			No mixing between batches in the farrowing, weaning and fattening sectors: yes score 1; no score 0				
3	Animal contact with contaminated premises	To prevent transmission of pathogens between age groups by premises	Standard Operating Procedures available and applied for "all out" cleaning, disinfection and duration of the empty period: yes score 1; no score 0				
4			Cleaning and disinfection of corridors and transfer zones after any animal transfer to prevent contamination of animals: yes score 1; no score 0				
5	Animal contact with contaminated staff	To prevent transmission of pathogens between age groups by staff	One-way organisation of work from the most susceptible to the most infectious animals (or separate sectors and staff): yes score 1; no score 0				
6			Change of clothes/overalls and footwear/overshoes between sectors: yes score 1; no score 0				
7			Change of gloves or hand washing and disinfection after handling diseased animals: yes score 1; no score 0				
8			Training of staff on the biosecurity Standard Operating Procedures: yes score 1; no score 0				
9	Animal contact with contaminated materials	To prevent transmission of pathogens between animals by materials and intervention	Suitable manipulable materials for environmental enrichment according to Recommendation (EU) 2016/336. Take note of the type of material (e.g. whole straw, chopped straw, hard wood, soft wood, rope of natural fibre, metal chain), quantity in kg/pig*day and frequency of distribution: yes score 1; no score 0				
10			Materials, movable equipment and tools specific to the different age groups: yes score 1; no score 0				
11			Cleaning and disinfection of materials, movable equipment and tools shared between sectors: yes score 1; no score 0				
12			Cleaning and disinfection of tools for interventions on piglets after birth in the farrowing sector: yes score 1; no score 0				
13			Dedicated injection needles for each age group of pigs or for every 10 heads individually housed (i.e. newly pregnant sows): yes score 1; no score 0				
14	High load of pathogens	To reduce the risk of exposure to high loads of pathogens	Regular cleaning of housing at all stages other than all in all out: yes score 1; no score 0				
15			Animal density of suckling, weaning, growing and fattening pigs, adapted to the weight of the pigs (see the "scoring instructions" in appendix section and take note of the type of pen floor inside the pig house: fully slatted floor, partially slatted floor, solid floor): lowest score of all stages				
16			Management of diseased animals to reduce contact with healthy animals (availability and use of hospital pens): yes score 1; no score 0				
17			Shower and parasite treatments of sows before entering the farrowing room: yes score 1; no score 0				
18	Heterogeneous herd immunity	To reduce at-risk situations due to heterogeneous herd immunity	Management of gilts before introduction into the herd with a contamination period in quarantine: yes score 1; no score 0				
20			Constitution of batches of sows with grouped farrowing note interval between batches): yes score 1; no score 0				
21			Constitution of pens of weaners and fattening pigs from full litters: yes score 1; no score 0				
22			Vaccination plan (consistent between consecutive batches in the medium and long term): yes score 1; no score 0				
23			Check access and intake colostrum by piglets to in the farrowing sector: yes score 1; no score 0				
24	Contaminated feed or water or enrichment material	To prevent contaminated feed or water or enrichment material	Controled origin and regular quality checks of feed: yes score 1; no score 0				
			Regular quality checks of drinking water: at least yearly for water sampled at drinkers score 1; at least yearly for water sampled at source score 0.75; otherwise score 0				
25			Controled condtions for conservation of feed including no access of rodents (inclusion of the pig house in the rodent control plan): yes score 1; no score 0				
26			Frequent cleaning of water supply equipments (take note of how and how often): yes score 1; no score 0				
27			Regular cleaning and disinfection of waterpipes and reservoirs: yes score 1; no score 0				
28			Concentrate feeds are salmonella free: yes score 1; no score 0				
29			Storage of materials on farm for at least 3 months before use (e.g. enrichment material like straw, wood): yes score 1; no score 0				
30			No use of food waste(e.g. enrichment material like straw, wood): no use score 1; use score 0				
		[a]write NA in column F if not applicable		**(higher score is less risk)**	*(max= **30** for all applicable conditions. Otherwise max score is calculated in F36 = applicable points)*		

OVERALL BIOSECURITY SCORE GREEN ZONE::	**0**
Maximum score	0
Percentage of maximum score:	**#DIV/0!**

BEAT table 6: Overall farm scores on biosecurity regarding the zones and transition lines between the zones

Final version 2023/03/21

FARM SCORES

Zones and transition lines	% of maximum score	(higher % is less risk)
RED ZONE	0%	
Transition line Red-Orange	0%	
ORANGE ZONE	0%	
Transition line Orange-Green	0%	
GREEN ZONE	0%	
Farm average score	**0%**	

BEAT APPENDIX: Instructions for scoring Animal density (Green zone sheet - line 15)

	Space allowance m2/head			
Scores	**0**	**0.25**	**0.75**	**1**
Pig category and live weight				
Piglets <10kg LW	<0,15	0,15-0,17	0,17-0,22	>0,22
Weaners 10-20 kg LW	<0,20	0,20-0,27	0,27-0,35	>0,35
Weaners/Growers 20-30 kg	<0,30	0,30-0,35	0,35-0,46	>0,46
Growers 30-50 kg	<0,40	0,40-0,50	0,50-0,65	>0,65
Growers/Fatteners 50-85 kg	<0,55	0,55-0,71	0,71-0,92	>0,92
Fatteners 85-110 kg	<0,65	0,65-0,84	0,84-1,10	>1,10
Fatteners 110-140 kg	< 1,00	1,00-1,12	1,12-1,29	>1,29
Fatteners over 140 kg	<1,00	1,00-1,29	1,29-1,47	>1,47