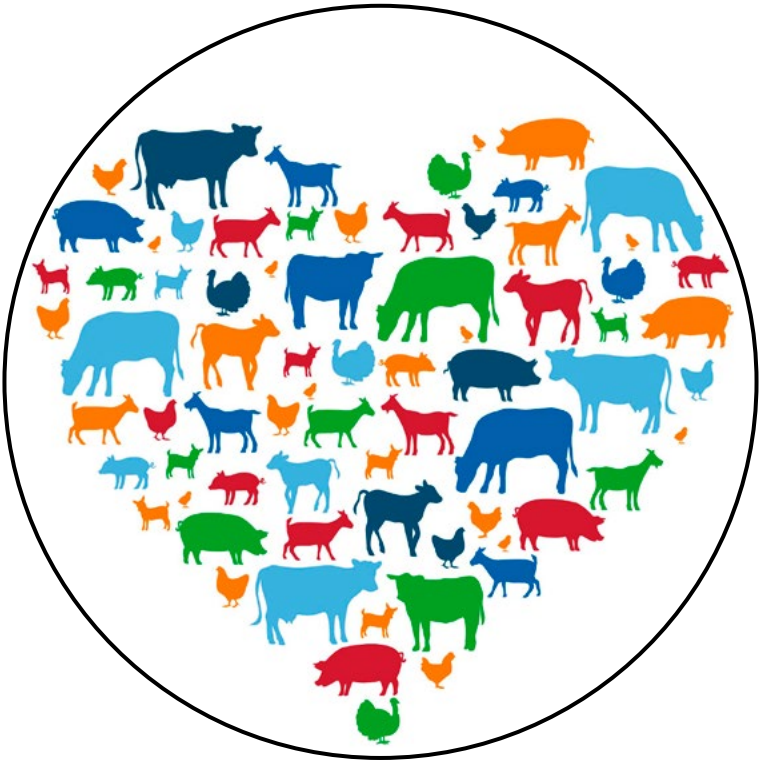

# Healthy and Resilient Livestock

Prof.dr Annemarie (J.M.J.) Rebel

Inaugural lecture upon taking up the position of Special Professor of Healthy and Resilient Livestock at Wageningen University & Research on 31 March 2022

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UNIVERSITY & RESEARCH

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# Healthy and Resilient Livestock

## Introduction

Esteemed rector magnificus, dear colleagues, family, friends, ladies and gentlemen. I am honoured to stand here before you in the auditorium of Wageningen University & Research to present my inaugural lecture as I take up the position of Special Professor of Healthy and Resilient Livestock. In this lecture I will explain the term resilience and how it can lead to improvements in livestock health. I will also be explaining my research plans.

After World War 2, the need to feed the world led us to design a food system that maximized productivity under standardized conditions. The main aim at that time was to achieve the efficient production of animal products, such as meat, milk, and eggs. Genetic selection was used to maximize productivity based on efficient feeding strategies. Costs were reduced as much as possible, for both farmers and consumers.

The need to avoid any form of disturbance resulted in vulnerable farming systems, with a reliance on high levels of bio-security to prevent the introduction of diseases. We designed a highly controlled housing system, including in the way we fed the animals, controlled feeding strategies. Animals were selected for their high and efficient levels of productivity.

Such an approach is often effective if the extensive technological requirements for controlling the system can be met. However, it's impossible to control every form of disturbance or to block it out of the system. Curative measures have therefore often been needed, such as the use of antibiotics to fight a bacterial infection. Or cutting the tails off of pigs to prevent tail biting.

Nowadays livestock production is the subject of debate, and is facing enormous challenges due to risks it poses to public health and because of its role in climate change. The license to produce is therefore under pressure. As consumers, we want healthy livestock production chains. We expect animals to be kept in conditions that prevent the development of diseases and other health problems. We demand higher welfare standards for animals, without the systematic use of antibiotics, and without tail docking or other physical interventions. And, we would like livestock also to have a minimal effect on the environment. Above all, we want to avoid risks to human health.

It seems that attempts to improve animal health and welfare are often framed by the need to increase productivity, and focus on controlling the system to prevent diseases. In recent years, animal disease prevention has relied on increasing bio-security. The aim has been to make sure that no transmission can occur between farms. When an outbreak does occur, protocols are in place, and depending on the outbreak – avian influenza, for example – positively diagnosed animals are killed. Restrictions are placed on the transportation of animals within defined regions.

These bio-security measures have indeed reduced infectious disease outbreaks. Alongside bio-security, animal vaccinations are used to prevent diseases, protecting them from specific viruses or bacteria. Over the past few decades, new vaccines for livestock have been developed that are easy to use and offer good protection against animal diseases. Having said that, there are still animal diseases for which no effective vaccines have been developed, and there are diseases – such as avian influenza – where the use of vaccines is the subject of debate. This is mostly because the virus or bacteria is rapidly evolving, or because it has a mechanism which makes it hard to tackle with a vaccine. New vaccines will also be needed as new diseases emerge in the future.

We have designed a controlled system, with high standards of health and where disturbance is blocked out. This type of system is widely used, and sits independently of the needs of individual animals, the flock or herd, and the farmer.

However even in a controlled system not all disturbances can be prevented. Besides that we don't know which kind of disturbances will come in the near future. So we should go from a controlled system to a system were the impact of a disturbance is diminished. So from a controlled system to a system were animals can adapt to new and unknown disturbances.

Animals need to be prepared for disturbances to production systems, and be able to respond and recover, regardless of the type of disturbance experienced. But how can we be prepared for disturbances of an unknown nature, and is it even possible to prevent every possible type of disturbance? Should we not start to think of possible solutions whereby animals themselves have the capacity to be prepared, and to respond in the right manner and recover?

We have to take into account that the types of disturbances encountered by animals are not limited to infectious diseases. Smaller disturbances can occur throughout the day, including ambient temperature changes, heat waves, transportation, changes in the kind of feed received, and a change from being with a mother drinking milk to eating solid feed. There will be yet more disturbances.

These will not be tackled with vaccinations or with biosecurity measures, but they do have an effect on the health and welfare of the animal. These disturbances will often impact the immune system and will therefore increase susceptibility to disease. So how can we design a system that is based not on control, and on removing all forms of disturbance, but on reducing the impact of any disturbance on animal health?
The vision of this chair is that the focus for new research into animal health should shift from the controlled approach towards a resilient approach.
Rather than only relying on vaccines and medication to combat specific infections or symptoms, this approach aims to increase the intrinsic capacity of animals and will improve their general health and robustness, thereby making them more resilient.

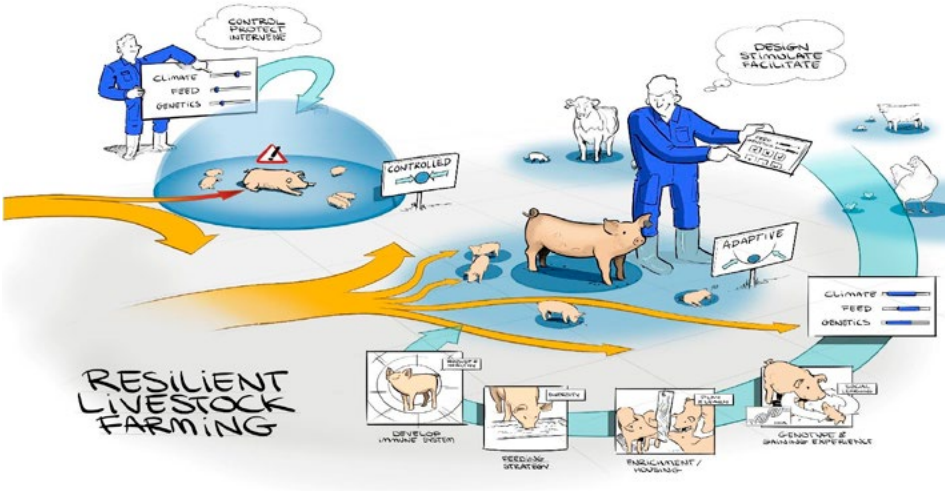
## Resilience

But first let me take you back to the last 2 years, to explain what resilience is and how it fits into improving the health of animals and decreasing their susceptibility to disease. As you all know by now – and as the coronavirus pandemic has reminded us – an infection can lead to disease. However, for some people the clinical signs of coronavirus infection were more severe than for others. Some people ended up in the hospital while others just had a minor illness and were up and about immediately. Those who displayed clinical signs, whether severe or mild, also had different recovery rates. Some people were only ill for a couple of days and could go on to run a marathon, while others needed a longer time to recover.

This difference in disease outcome can be associated with the resilience of the individuals. Susceptibility to a disease or to other disturbances, and the ability to quickly and fully recover, is the result of the resilient capacity of an individual. You are resilient when, following a disturbance, you are able to return to the level that you were before the disturbance.

The outcome is therefore dependent on individual responses and not simply to the severeness of the disturbance. Individuals infected with the same virus or subjected to the same heatwave will react differently. The biological mechanisms of the immune system, the metabolic system and the behavioural system respond differently, and therefore disease outcomes will differ from one individual to the next.

The capacity of an individual to be minimally affected by disturbances or to be able to quickly recover is called resilience. It means that for the duration of the disturbance resilient individuals are able to maintain essentially the same functions, and biological




mechanisms will maintain the same structure and feedbacks. Resilience at the level of individual animals can be described as the ability of an animal to react or adapt to changing conditions or potentially stressful disturbances with minimal loss of function.

Can we use resilience to prepare livestock for different types of disturbances? Not only for different types of infection, but also when their feed is changed, during heatwaves, or for any other disturbances? This implies a change in our thinking, going from a system in which we aim to diminish threats in a controlled setting, towards a system where animals and farmers can reduce the impact of disturbances.

This is why attempts to improve animal health call for attention to be paid to resilience. In a resilient system the focus is not on maximizing production, but on specific animal needs related to health and welfare. Welfare is not only the absence of negative behaviour, such as aggressive behaviour, but also positive emotion.

Can we design systems where the animals are in a positive mood, seeing the glass half-filled and not half empty? And does this have a positive effect on resilience? Can the system be optimized according to animal needs? The idea behind this is that the animal can better deal with disturbances when the system is designed on the basis of the animal's

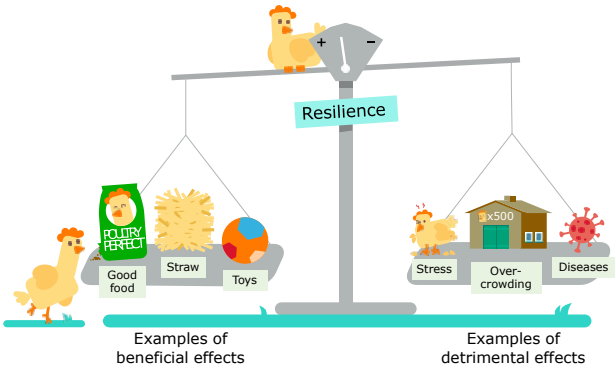
ability to respond. In a resilient system, animal health is less dependent on control. Instead, the intrinsic capacity of animals is developed to react within a certain bandwidth of fluctuations, so that the impact of disturbances will be minimal.

The development of the intrinsic capacity can be influenced by management practices like feeding strategy, environmental enrichment and housing system, genotype and gaining experience, and development of the immune system. The system is not completely open, but less controlled. The farmer is able to respond and change management practices and animals are able to adapt to different disturbances.

More resilient livestock farming will have higher levels of animal health and welfare and this can lead to further reduction in the need for antibiotics. A reduction in the susceptibility to disease will in turn reduce the spread of infectious diseases.

This intriguing concept of resilience could be used to design systems where animals are able to adapt and to cope with disturbances and to recover from them. Are animals born with a certain degree of resilience or is it possible to influence this? There is a delicate balance between health and disease, and it is possible to affect this balance. The question of which of the biological mechanisms can be influenced – so that the balance is affected in the desired direction – is something that needs to be investigated.

The capacity of animals to respond after a disturbance depends on the function of immunological, metabolic and behavioural processes. These processes are the intrinsic capacity of the animal. For an animal to be resilient, the intrinsic capacity of these



immunological, metabolic and behavioural (physiological) systems needs to be fully used. It is known that the development and the function of these physiological systems can be influenced, either through beneficial or harmful factors.

## AIM

We study the underlying mechanism of the intrinsic capacity of animals in order to find methods to improve resilience. This can give us an understanding of variations in how individual animals respond to different disturbances, whether they be pathogens or stressful transitions. With this knowledge, we can re-design systems using the factors that positively affect the intrinsic capacity, directing the balance in the desired direction.

This shows that different factors can influence the development and the function of different biological systems, making it possible to influence health and disease susceptibility. This is called a resilient system, one that is based on the needs of the animal. Rather than being a controlled farm, it is a customized farm.

I will show some examples of the work we have performed in which we have looked at external factors that influence immunological development and the balance of health and disease. We are studying opportunities to improve health, by influencing the animal's own intrinsic capacity through factors such as feed, environmental enrichment, housing systems, gained experience, microbiome and immune development. We will investigate what the underlying mechanisms are and how this can lead to resilient animals. This is not instead of bio-security and vaccination, but alongside bio-security and vaccination. To enable animals to deal with a variety of smaller disturbances, to be prepared and able to recover: the adaptive situation.

## Influencing resilience

**Feed and feeding strategies**

As Hippocrates said back in around 400 BC, all disease begins in the gut. Nowadays we translate this to "you are what you eat". We know that our health is influenced by our diet. In the past, this was typically evident in the form of illness caused by deficiencies, such as scurvy (scheurbuik). When sailors went on voyages of discovery, 50 percent would die of scurvy on those long trips to the east.

In the 1700s, it was found that scurvy resulted from sailors not eating fresh vegetables, and that this could be treated with citrus fruit. The Navy was advised to give lemon juice to its sailors. This dietary supplement addressed the Vitamin C deficiency that caused the

disease, and the problem was solved. So, shortages of specific nutrients can result in disease. However, food can also actively promote good health and have an effect on immune development and therefore on resilience.

The intestine is made up of host cells responsible for the digestion and absorption of feed ingredients and consists of immune cells. The intestine is a large immune tissue. In the lumen of the intestine are bacteria, the intestinal microbiome. Most of the time, those bacteria are harmless and will help digest and process the feed. Because the bacteria are interacting with the host tissue, this interaction will influence immune development. When studying intestinal health we should look at the microbiome, the immune cells and other specific functions of the intestine. Research has shown the importance of the interaction between the intestinal immune development and the microbiome colonisation in association with feed. The development of the immune system of the intestine is of importance because the intestine is in direct interaction with the outside word and is therefore known as the "gatekeeper" of health. Modulating the microbiome or immune development could help improve intestinal health, thereby increasing resilience.

In his PhD research, Dirkjan Schokker studied intestinal development with gene expression techniques (Schokker et al., 2013). Using this approach he investigated biological processes and mechanisms in the intestine. He took a systems approach, combining data to unravel the processes of intestinal development. After his PhD he studied the interaction of the microbiome and intestinal development (Schokker et al., 2015 & 2021).

In the early stages of the life of livestock, microbiota is colonising the intestine while at the same time the immune system is being developed and trained to react or not to react. It is primed to know the difference between a disturbance and "good" food. This means that every time you eat something new, the intestine doesn't have to react as if the food is a problem which needs to be defended against.

The microbiome composition of the gut, and immune development, are both influenced by the type of diet or feed given in early life. This early feeding will have long-lasting effects on biological mechanisms through the development of the intestinal immune system. We and others have shown that there is a window of opportunity in early life to influence the microbiome composition and intestinal development.

Results in several studies and different animal species have shown long-term consequences in intestinal immune development when changes in feed occur early in life. So changes to

your diet composition when you are young will influence your intestinal development for a long-lasting period. When you change your diet composition later in life, after most biological processes have been developed, immune cells will still be influenced, as we have shown, but this is not long lasting. Your immune cells will bounce back to the level they were at before the change in diet. Thus, only temporary effects are being induced. Specific nutrients in food can contribute to improving the development of the immune system. A resilient microbiome can result in improved animal resilience.

In an older study, as part of Saskia van Hemert's PhD research, we investigated whether the diet of hens had an effect on the susceptibility of their offspring to disease (Rebel et al., 2006). It was striking that the diet of the mother animals had an effect on the intestinal development of the offspring. This difference to the intestine development were long-lasting. There were differences due to the feed of the mothers in the processes related to the growing and maturation of the epithelial cells of the intestine and the intestine's immune processes differed. These differences in intestinal development also affected the outcome of an infection.

Recently we investigated whether specific feed ingredients in the diets of mother pigs influence intestinal development, including the microbiome composition of the piglets (de Greeff et al., 2020). We compared intestinal development with the development of the intestine of piglets which received similar feed ingredients. So the piglet received the specific ingredients either via their mother, or directly in their own feed. Changing the piglet's diet early on in life did change the intestinal development at the immune development level and at the microbiome level. Also, when the mother's diet changed, this influenced the microbiome composition and the intestinal immune development of the piglets. However, these influences were not the same as when the piglets were fed directly.

This tells us that food influences the microbiome composition and intestinal immune development, with possible effects on the resilience of the animals. However, the effect depends on whether the food comes via the mother or is given directly to the piglets. Influences that affect the offspring via mother are called epigenetics, and these could give some additional tools to influence resilience. This will be the subject of a future research line in collaboration with Henry van den Brand of the Adaptation physiology group.
New research directions have been set up with the group led by Ingrid de Jong to look at associations between the microbiome of the gut and the behavioural system. Studies have shown that microbiota influence aspects of the host's behaviour, such as anxiety and stress. These effects mean that microbiota could change an animal's ability to cope with disturbances. The underlying mechanisms by which gut microbiota affect the brain are largely unknown. It

is clear, though, that metabolic, immune and neural pathways will be essential. We have studied whether this gut-brain axis could be influenced in livestock. Preliminary data has shown that a positive environment could influence the microbiome of chickens. This means that the brain-gut axis could be used to effect resilience and to influence welfare and health. Further research is being done to associate specific bacteria strains, or groups of bacteria, with changes in behaviour and immunological development and resilience.

**Environmental enrichment and housing**

Ingrid van Dixhoorn's PhD research looked at whether resilience can be influenced by management practices. Animals are often housed in farms with fairly barren conditions, even though we know that a more varied environment is beneficial for welfare and health. This led to the idea that an enriched environment may make animals more resilient. The influence of social and environmental enrichment in pigs was studied. This type of environmental enrichment for animals on the farm is important for their well-being. Good social and environmental enrichment enables animals to express their natural behaviour.

Ingrid van Dixhoorn has shown that housing pigs in enriched farm conditions differed in their immune development when compared to conventionally housed pigs (van Dixhoorn 2016). Differences in the immune cells of the lungs and blood were observed. Pigs that were kept in an enriched environment were less susceptible to viral and bacterial infection in the lungs. Those pigs were also able to recover faster. When we investigated the gut of these pigs, we found that there were differences in the microbiome composition. This means that housing has effects on the microbiome and on immune development and behaviour, with positive effects on the resilience and disease susceptibility of the animals.

The next question Ingrid asked is whether there is a relationship between animal-based measures introduced before the onset of disease and their susceptibility to such disease. How prepared is an animal? She proposed a model based on animal-specific measurements that could predict the severity of an infection (van Dixhoorn et al., 2021). Further research, together with Liesbeth Bolhuis of adaptation physiology group and Kees van Reenen of Wageningen livestock, will be used to study additional animal based biomarkers that could predict resilience.

**Vaccination strategies**

Young animals are susceptible to infections, and vaccination soon after birth could therefore improve disease prevention. Because the immune system develops during early-life, the vaccination of young animals is less successful at the moment than that of adults. In her PhD research, Sandra Vreman showed that vaccine formulations could be specified for particular

ages and administration routes (Vreman et al., 2021). Skin vaccination is a promising method for triggering immune cells in pigs. Also, the PhD research of Evelien de Geus, in collaboration with Lonneke Vervelde of the Roslin Institute in Edinburgh, showed that in chickens administration routes and vaccine formulations are of importance for specific immune responses (de Geus et al., 2011). Willem Swinkels' PhD research showed that there is an age dependent response after Eimeria infection in chickens. Sandra Vreman, in collaboration with Norbert Stockhofe, showed that triggering lung cells with an non-specific agent decreased the onset of an Eimeria infection in the intestine. It seemed that the immune system is being trained. The cells are more primed for action, compared to the untrained cells. This triggering of the innate immune system, including the cross talk between the lung and intestinal tissues and immune cells, could be used to influence resilience. Collaborations with Henk Parmentier and Aart Lammers of the adaptation physiology group and Norbert Stockhofe and Christine Jansen of Wageningen University and Research will help us unravel the mechanisms by which programming of the immune system can be used in the resilience of animals.

**Combining of factors**

Further research will combine the different factors that, as we showed, influence resilience. We will investigate the effect of feeding strategies and the influence this has on the microbiome in relation with a vaccine response and disease susceptibility. Also the combination of environmental enrichment together with feeding strategies will be studied as customized management practices to influence resilience. This in order to find whether animals will be resilient for different disturbances where either more the immune system or the metabolic system is challenged. Future research includes investigation on the underlying mechanisms of resilience. Relations and interactions between different physiological systems, like the immune and behavioural system, will be related to resilience. If recovery rates of different physiological systems are jointly positively affected (cross correlation between systems), we can influence general resilience. Thus, we will determine whether external factors could affect the interaction between different physiological systems. The possibility to cope with more and different disturbances will give an indication whether combined external factors, like housing and feeding systems, affect the resilience and recovery potential in the broad sense of resilience.

## Measuring resilience

It has been difficult to quantify resilience directly. We often look at the response before and directly after a disturbance, at one single point in time. However, when disturbances are smaller, and not as defined as an infection, when do we measure? The disturbance can take

place just after you have measured or just before. More measurements are then needed to be able to characterise resilience, as resilience is defined as the ability to cope with a disturbance.

The hypothesis is that animals with low resilience show more variation over time in the measured physiological parameters. This is because both recovery times and the effects of various perturbations increase. Therefore, time-series analyses of biologically relevant data should be used to monitor resilience. The difference in variation in the time-series analyses, due to smaller disturbances, should then be related to health and welfare. Thus, to quantify resilience, we need to use monitoring tools and biomarkers that can be collected frequently. With sensors that can measure 24 hours a day and 7 days a week, like your smart watch, we will be able to measure all changes over time. This will enable us to detect very small disturbances too.

These sensors will allow us to analyse the dynamics of physiology and biological parameters and to relate these to health and welfare outcomes. This will result in a flood of data, out of which resilience could be quantified using new big data analysis tools and algorithms. If we analyse the data we will see a pattern of micro-recoveries after different natural disturbances. Such dynamic indicators of resilience may be used to monitor early changes in the animals.

But will it be possible to predict resilience? Could we assess the influences of feed or housing on resilience? We think that different types of sensor and data sources will be needed for that. Sensor technologies have great potential to monitor the health and welfare status of animals, and to provide an early warning signal when resilience is reduced. Sensor technologies have been developed that continuously, in real-time, measure indicators in animals, groups of animals, and the environment.

Research is needed to develop models that can detect deviations in normal patterns of behaviour, posture, sound, and the physical condition of individual animals and groups. In the near future, research will need to focus in particular on modelling and developing algorithms for combinations of sensors. In order to detect deviations from what is 'normal', we will need more than single sensor signals. These combined data analyses, drawn from different sensors, will enable us to detect impaired resilience.

New PhD research is expected to start to develop and use novel algorithms to analyse partly automatically recorded sensor data. This will be used alongside manual measurements and biological sampling, based on the physiological and behavioural and health data of individual animals. The goal of this PhD research will be to identify early

warning signals which are indicative of the resilience of the animal. Early signals may be subtle or non-specific, a pattern of micro recoveries, and may only be derived from a combination of various data sets.

The focus is to better understand the intrinsic capacities of the physiological systems of animals that contribute to resilience. This will enable the development of non-invasive real-time tools for measuring and monitoring the intrinsic capacity of physiological systems and the resilience of animals. Based on this understanding, we will be able to implement management and environmental approaches that allow animals to better cope with challenges, leading to improvements in their health and resilience.

## Resilience in livestock

The Netherlands is a densely populated country with a large agricultural sector where we need to protect our unique natural landscape and restore its biodiversity. The Dutch government aims to be an international frontrunner in sustainable circular agriculture by 2030. The vision is that livestock farming must become even more sustainable and animal-friendly than it already is. To achieve this, we need to produce as little waste as possible and reuse as much as possible. For animal feed production, this means a shift away from using proteins that could otherwise be consumed by humans, and using locally sourced products to replace soybean. For example, use waste streams of the feeding industry or use insects as protein source. It's important to be able to guarantee the safety of feed and food as part of this transition toward circularity, and animal health and welfare must also not be negatively affected. The council of animal affairs was asked to make a "zienswijze dierwaardige veehouderij" – a dignified livestock sector. In doing so, the council was calling not just for the safeguarding of animal welfare and health, but also recommending that positive welfare be an inherent part of agriculture.

Wageningen University is part of a collaborative project to the transition towards circular food systems, working with the government, provinces, and cities, along with the farmer organisation LTO-nord, the University of Utrecht in a living lab of farmers. This project – the Regiodeal Foodvalley, sustainable agriculture. – is focusing on accelerating the development of the primary sector towards sustainable and circular agriculture. Within this project, PhD students Vivian Witjes and Fleur Veldkamp will investigate the effects of circular feed on animal health and welfare. They are doing this in collaboration with Arjan Stegeman's group at the University of Utrecht. The PhD candidates will develop sensors to measure resilience, health and welfare. It is important that resilience and animal welfare and health are not compromised when these circular feed concepts are applied. When estimating health and welfare levels, behavioural indicators are particularly important because variation in behaviour represents the first adaptation to distress in animals. Novel

non-invasive sensor technologies are able to monitor animal behaviour. This can be applied at a larger scale and is therefore a more reliable way of detecting variance in recovery after small disturbances.

The aim of Fleur Veldkamp's PhD project is to use non-invasive sensor technologies to assess the resilience and welfare of pigs, applied in circular feed experiments. Sensors need to detect the use of environmental enrichment material by pigs and the general activity level of pigs. Vision, position, and other non-invasive sensor technologies will therefore be combined with manual measurements. This analysis will also take the microbiome composition into account.

The aim of Vivian Witjes's PhD project is to use biomarkers and non-invasive sensors to measure positive welfare in pigs. She will focus on finding biomarkers that are associated with the emotional state of pigs. Is the glass half full or half empty? She will, therefore, study whether circular feeding concepts do affect positive welfare via the gut-brain axis. Fleur and Vivian will analyse the sensor data on deviations in the potential to recover from naturally occurring disturbances as an indicator of resilience. This will be associated with the different feeding concepts, and compared to the conventional feed concepts.
In the regiodeal foodvalley also, solutions for the reduction of emissions will be investigated. One option for achieving a reduction of emissions such as nitrogen and methane is to reduce the livestock sector. But having fewer farms does not automatically mean that the remaining livestock will be healthier and more resilient and that emission is reduced in the remaining farms. In these projects we integrate research on emission and animal health. This is to ensure that emission reduction technologies don't adversely affect animal health.

Other options than emission reduction technologies is the idea that variations within farms and management practices can potentially give insights in the role of management-based emission reduction. As part of his PhD research, Marien Korevaar will work with Albert Winkel of Wageningen Livestock Research and Dick Heedrick of the University of Utrecht to continuously measure emissions like ammonia and $CO_2$, but also temperature and humidity. These sensors that are able to continuously measure emission will be used on different farms where different management practices are in place. Alongside this, he will develop a sensor that will be able to continuously measure fine dust, which affects both human and animal health. A new data methodology will be developed to relate ammonia emission, fine dust emission and environmental conditions with management practices. This data will give insights into which management practices influence emission. This will be related back to animal health and welfare parameters and will be associated with differences in on-farm management practices, such as feeding and vaccination. The PhD

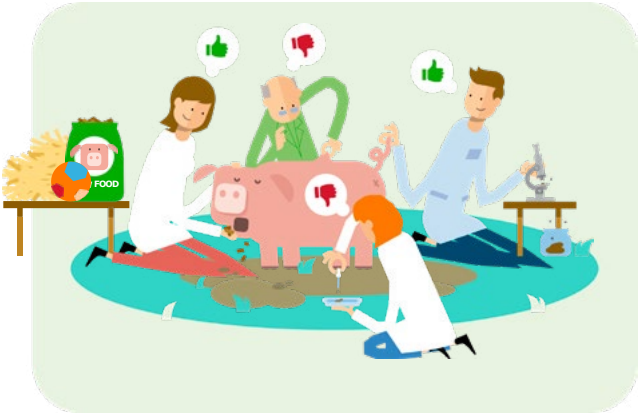
candidates will work together to use the obtained data and investigate whether emissions are related to animal health and welfare, and how management practices and emissions are related or could be used as resilience indicators.

The initiated transition of the agri-food sector also need to focus on the health risks that may arise from these new concepts. Circular feed and new management practices to improve resilience could have consequences for the introduction and spread of bacteria and viruses. From a One Health perspective we need to design an animal production system with less impact to human health risks. Together with the Netherlands Centre for One Health, the NCOH, we will combine expertise on human and animal health. The NCOH is a network of nine academic research institutes that take responsibilities to find answers to one health challenges. Together with the NCOH partners, we will study possible side effects for human health in the transition of the livestock sector.

## Collaboration, because resilience is not a single issue

This Special Chair at Wageningen University for healthy and resilient livestock will stimulate crossovers between different fields of expertise. By combining disciplines, we can optimise the capacity of animals to achieve improvements in health, recovery, and resilience. Resilience is a broad topic that brings together a range of different disciplines. We should not narrow our focus to investigating single aspects and solutions. If we investigate single factors looking at a single outcome, we can conclude that a pig will be healthy or not.

We might give the factor either a thumbs up, or thumbs down, without taking the whole pig into account. The aim of this chair is to bridge the various kinds of expertise needed to

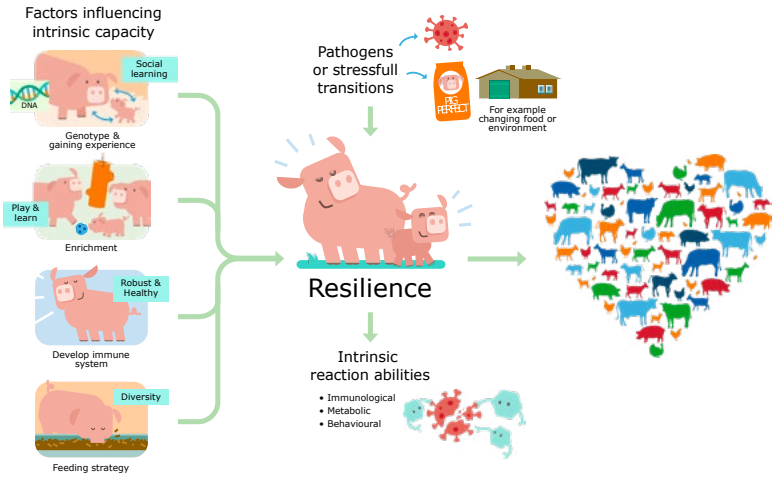


investigate the underlying mechanisms for achieving healthy and resilient livestock through collaboration. This means investigating biological factors that do not sit independently of each other.
Immunology systems interact with metabolic systems, behavioural systems, and other systems. Changes to one of these biological mechanisms will influence others. This illustrates how collaboration is vital if we are to look beyond single factors and take an integrative approach. Such an integrative approach will reveal factors that influence resilience and resilience indicators.
With data-driven science and new monitors, algorithms, sensors, and measuring tools, possible 'trade-offs' and synergies between interacting biological systems, environmental factors, and resilience can be examined. Therefore, as mentioned earlier, new sensors will be developed which are able to take measurements at multiple points of time, and can measure health, welfare, and the resultant resilience. A new NWA project, just granted, will develop a sensor that will be able to detect on the basis of odour differences in the microbiome. This is a collaboration between the technical universities of Delft and Enschede and the group of Francisca Velkers of University of Utrecht. Collaboration between expertise in animal science, human health, infectiology, microbiology and data science is needed to investigate the underlying mechanisms of resilience in health.

## Conclusion

The concept of resilience is as follows: Support animals in the capacity to adapt to changes where possible, and protect and vaccinate them where necessary. The ability to adapt can be influenced by housing, nutrition, microbiome and vaccination strategies, and development of the immune system. Non-invasive sensors will be used to investigate whether resilience is affected. This will result in new insights into how feed, microbiome, early life, housing, and management practices affect the balance of health and disease, and thus resilience.

Certain factors can optimise this balance of biological systems within animals and contribute to the resilience of animals. The main aims for the coming years will be to understand the mechanisms causing variations in responses between individuals within a population after a disturbance, and how the balance between health and disease could be influenced.
Resilient livestock farming is urgently needed in order to achieve sustainable animal production in the future without unnecessary use of medicines. The proposed research lines will lead to animals that can better cope with disturbances, resulting in a reduction in the use of antibiotics and medicines, fewer disease outbreaks, and better welfare. Ultimately, this will also have positive effects on public health.




I hope to add a new dimension to the field of animal health. The field of healthy and resilient livestock will allow a more holistic approach in both research and education, leading to a deeper and broader understanding of animal health in the livestock sector. It will enable the development of innovative methods to increase health and resilience by influencing the intrinsic capacities of animals to respond to disturbances. A reduction in the potential public health risks arising from livestock production – such as the transmission of zoonotic pathogens, and the transmission of antibiotic resistant micro-organisms – can be achieved by optimising and improving animal health without the systematic use of antimicrobials. This research will also impact social perceptions of animal farming.
Healthy livestock is an important research topic within the One Health theme, a novel approach to health issues which is rapidly gaining interest among human and veterinary medicine students worldwide. In the near future, targeted adjustments to resilience could contribute to healthy animals and potentially to a one health approach.

## Acknowledgements

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*Individual animals react differently to similar challenges. Animals relatively unaffected by the challenge or quick to recover are resilient. We will bridge different expertise to unravel the underlying mechanism of resilient animals. Biomarkers and sensors will be used to investigate resilience. The aim will be to understand mechanisms causing variations in responses between individuals after a disturbance. How the balance between health and disease could be influenced. Resulting in resilient animals with a positive effect for animal and human health 'One health'.*

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