Litter management to support chicken meat production and industry growth

by Mark Dunlop and Claire-Marie Pepper
July 2023

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Chicken Meat

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Foreword

The Australian chicken meat industry is continually improving management practices in poultry sheds to ensure the best possible animal health and welfare, product quality and industry sustainability outcomes. This project focused on litter management, especially practices that disturb litter. Litter tilling is a management practice used by most Australian meat chicken growers to ensure chickens have access to friable litter that provides them with cushioning and insulation, and allows them to 'work' droppings into the litter.

Australian growers have been tilling litter for years and, through practical application and experience, have refined their methods and improved their understanding of best practice application. However, the practice of litter tilling is not common in the global context and there is very little reported knowledge on how litter tilling influences litter conditions and affects environmental outcomes, including the release of ammonia and odour.

The purpose of this research was to record the experiences of chicken meat growers with managing litter, with a focus on litter tilling. The effects of litter disturbance, including tilling, were then quantified in terms of litter conditions, ammonia and odour. Successful litter management requires a whole-of-system approach and a variety of tools and strategies that growers can use and adapt in the highly variable and dynamic environment in which they operate.

This project was completed as part of the AgriFutures Chicken Meat Program, which aims to improve environmental outcomes and sustainability; enhance chicken biosecurity, health and welfare; contribute to efficient and secure production systems; ensure the food safety of Australian chicken meat; and build people capability and a skilled, diverse and sustainable workforce. For more information and resources, visit agrifutures.com.au/chicken-meat.

John Smith
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AgriFutures Australia

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Executive summary

Background

The Australian chicken meat industry uses modern husbandry, technology and production methods to efficiently produce Australia's favourite and most affordable meat. Per-capita consumption of chicken continues to increase, which fuels the need for industry growth but also requires refinement of on-farm practices to ensure efficient, safe and ethical production. The industry is in most Australian states, with production occurring in vertically integrated businesses that coordinate all aspects of production in breeding farms, hatcheries, feed mills, abattoirs, transport and grow-out farms. Production is concentrated in regions that experience a range of climatic conditions, which influence management and husbandry practices.

This project focused on litter management in grow-out sheds, where day-old chickens grow for five to eight weeks until they are loaded up and transported to an abattoir for processing. Grow-out sheds have an open-plan layout and the floor is covered with soft, insulating and absorbent bedding material known as litter. During the grow-out period, chicken droppings are added to the litter and are 'worked' in by chicken activity. A substantial amount of water is added to the litter via the droppings but also comes from other sources, such as the drinkers.

One of the most important aspects of litter management is regulating moisture content to ensure chickens have access to litter that is dry and friable. Dry and friable litter tends to have favourable physical properties and provides better air quality in grow-out sheds, although excessively dry litter can increase the amount of dust. Providing litter that is mostly dry and friable helps to reduce potential risks relating to chicken health and welfare, worker safety, odour impacts and food safety pathogens.

Developing resources for litter management practices

When this project was conceived, the chicken meat industry had few resources that outlined best management practices (BMPs) for litter and litter re-use. The *Best practice litter management manual for Australian meat chicken farms* was later published by AgriFutures Australia. It outlined many practices but there was a need for more information about the practical, industry-proven options to keep litter drier, improve friability, reduce water spilled from drinkers and generally reduce risks associated with wet litter.

With such a complex and dynamic production environment that has many variables, and where timing is of the essence, growers need a variety of practices that suit their specific situation rather than a limited number of prescriptive BMPs. This project aimed to provide complementary research to the practices that growers have developed and refined over the years, and improve understanding of the physical and chemical processes associated with litter management practices.

To get a snapshot of current litter management practices and challenges, an industry survey was sent out and growers were asked to share their experiences. Combined with guidance from an industry committee, some litter management themes were prioritised and a series of fact sheets, case studies and procedures were produced, including:

- Drinker management
    - Adjusting height and pressure to reduce spillage, cleaning and flushing to reduce leaks, replacing worn drinkers and installing medium-flow drinkers
    - Procedures to measure drinker flow rate and adjusting pressure based on conditions

- Keeping litter friable and 'working'
    - Litter assessment (using the *Litter Guide – Daily litter condition assessment*).
    - Litter tilling methods and experiences of tilling different litter materials
- Dry litter and ventilation
    - Elements of drying litter (heat, air speed, water available to evaporate)
    - Shed pre-heating and drying litter prior to placing day-old chickens
    - Circulation fans.

The fact sheets were intended to be a resource for growers, stakeholders and those who are new to the industry. It is important for this information to be readily available because growers generally have limited opportunities to see techniques and practices being used on other farms. During this project, a litter-focused webpage known as *Litterpedia*, to be managed by AgriFutures Australia, was developed and will be a repository for information relating to litter. In addition to these fact sheets, a 'trouble-shooting guide' was also prepared that can be incorporated into *Litterpedia* to help users find the information they need, including links to relevant resources.

Effect of litter management on odour, ammonia and carbon dioxide

Litter tilling (also known as litter turning, stirring, or conditioning) is a litter management practice commonly used in Australia. The industry survey showed nearly 90% of growers perform litter tilling on a scheduled basis or in response to the litter surface becoming crusted/caked with manure. Tilling is not as common in other countries due to concerns about the potential for it to increase ammonia concentration in the shed or contribute to injuries if not managed in an appropriate way.

Litter tilling mechanically loosens compacted litter, improves friability and reduces the occurrence of wet litter in the short term by mixing it with surrounding dry litter. Litter tilling needs to be combined with effective ventilation and drinker management to deliver longer-term benefits. Risks associated with litter tilling relate to operating machinery within the shed and the accelerated release of ammonia and other aerosols, which may cause a 'spike' in concentration that can impact chicken welfare if not managed appropriately. Growers already understand ammonia is a challenge during tilling, and they increase ventilation to reduce the concentration that chickens are exposed to; however, there is limited understanding about ammonia strength, how long the 'spike' lasts, and the effects of litter moisture, caking, re-used litter and litter age (based on the number of days in the grow-out).

Ammonia concentrations

Observational experiments were undertaken in commercial meat chicken sheds in South East Queensland to measure ammonia (NH_3) concentrations during and after litter tilling. Additionally, ammonia emission rates were measured directly from the litter surface to isolate the effects of litter conditions and ventilation. Ammonia 'spiked' after litter tilling but rapidly subsided within a few hours, although some longer-term, low-level increase in ammonia concentration occasionally persisted for up to 24 hours. Ammonia concentration related to daily trends in ventilation rate and the age of the chickens and could be managed with additional ventilation. Any longer-term effect of litter tilling on ammonia concentrations could not be determined due to many other influencing factors.

Carbon dioxide

While tilling the litter caused the ammonia concentration to increase in the shed, there was no effect on the concentration of carbon dioxide (CO_2).

Odour emission rates

Prior to this research, some development applications for proposed meat chicken farms were being hampered by concerns that high odour emission rates (OERs) may occur during routine activities, such as tilling, pick-ups and shed clean-out. There was an absence of OER data during these events and therefore a need for OER to be measured.

Odour samples were collected from 16 meat chicken farms during litter tilling (n=8 events), chicken catching/pick-up (n=4) and litter heaping/cleanout events (n=2, where litter was removed from the shed at the end of the grow-out). They were collected before, during and after each event to investigate OER trends. Samples were collected from a treatment shed where the event was taking place, and a neighbouring shed that was undisturbed. OERs were calculated on a ‘per 1,000 birds placed’ basis. The OERs measured before, during and after event were statistically analysed with the means of each time point being compared.

During litter tilling, pick-ups and cleanout events, odour emissions from the treatment shed increased relative to the control shed, although the increase was difficult to quantify due to normal changes in the OER during each day and due to multiple influencing factors that differed between the control and treatment sheds. Due to this being an observational study conducted at commercial farms, control and treatment sheds were matched as closely as possible but there were often differences in chicken age, stocking density and litter conditions.

The OER increased significantly in both the control and treatment sheds when the litter disturbance event was occurring in the treatment shed (even though there was no disturbance in the control shed). The main finding from the OER measurements was that they only increased by approximately 20% in the treatment sheds, relative to the control sheds, as a result of the litter disturbance. Also, any increase in the OER dissipated quickly and there were no numerical or statistical differences between the treatment and control sheds three hours after the tilling, pick-up or clean-out were finished.

Caution needs to be exercised when measuring or interpreting OERs when substantial changes are occurring in the sheds, such as a reduction in chicken numbers during a pick-up, or growers manually controlling ventilation in a shed during litter cleanout. These situations cannot simply be compared to a neighbouring shed where the changes are not occurring and cannot be compared to the situation ‘before’ the litter disturbance occurred. Due to the difficulties in controlling on-farm conditions, accounting for daily fluctuations in the OER, and finding sheds that are truly comparable for odour measurements, we recommend that OER measurements during short-term shed management activities should not be repeated in the future.

Simulating litter moisture conditions

Managing litter moisture content is important because it affects the insulating, cushioning and water/manure absorbing properties of litter. Moisture content also affects the potential for ammonia, odour and dust emissions. Water additions, evaporation and the resulting changes to moisture content are dynamic, complex and inter-related processes that are affected by multiple factors. It would be beneficial to model the litter management practices and their effect on littler moisture content. Computational models allow the assessment of different practices and technologies on litter conditions under a variety of production, climatic and weather conditions. In this project, theoretical and empirical calculations were combined with meat chicken production data and on-farm environmental and ventilation data to develop two computational models, including a pre-placement litter drying model and a litter moisture content simulation model.

We used the pre-placement litter drying model to demonstrate the effects of different heating, ventilation and litter tilling strategies on reducing litter drying times. The model showed that using a combination of all three strategies was the most effective. In comparison, applying only one strategy required extreme levels of heat, ventilation or tilling frequency to make even a moderate difference to drying time. Translating these findings to real-world situations, the combined approach would increase water availability, evaporation rate and removal of the water from the shed to maximise evaporation. Calculations in the pre-placement drying model were programmed into a mobile app called '*Litter drying time calculator*' by the University of Georgia, which can be freely downloaded. The app allows users to change shed heating temperature and ventilation rate to estimate how long it will take wet bedding to dry.

The Litter moisture content simulation model commenced development during this project and requires further development and validation. It has been used to predict the litter moisture content at two farms, where actual litter samples confirmed that the model predictions reflected reality. The model was used to predict the effect of different litter tilling intervals and the addition of circulation fans on litter moisture content. It showed that increasing air circulation and air speed helps to keep litter drier, especially in the first three to four weeks of a grow-out.

The model also showed that judicious use of litter tilling may reduce litter moisture content. We recommend that the *Litter moisture content simulation model* continue to be developed and validated using on-farm litter moisture assessment and downloaded shed ventilation data. The modelled predictions of the effect of circulation fans on litter moisture content aligned with previous overseas research. It is therefore recommended that circulation fan systems (especially those that produce air speeds of approximately 0.8–1.0 m/s at the litter surface) are researched and developed to support industry awareness of the technology and address any challenges that might arise with their use.

Implications and recommendations

The industry survey captured a snapshot of litter management practices being used by Australia growers, with a focus on litter re-use and litter tilling. The survey showed that only about a third of growers have any experience with re-using litter. Growers shared their experiences about litter tilling, reporting that it does not achieve dry and friable litter on its own and that proactive ventilation and heater and drinker management are essential. Growers also explained that litter tilling is not without its challenges, and can potentially contribute to spikes of dust, ammonia and/or odour, as well as being difficult to conduct when there is high live-weight density.

Based on these responses, it was recommended that more resources and training be developed on ventilation and other management practices aimed towards achieving dry and friable litter. It was also recommended that the industry focus on the current barriers to litter re-use and provide support and training for growers wanting to adopt the practice, so that they can improve their farm's sustainability, litter management, resource use efficiency and profitability, while also minimising risks.

A comparison of litter moisture content to condition scores described in the *Litter Guide – Daily litter condition assessment* has shown that this method allowed litter conditions and moisture to be quickly assessed on commercial farms. We recommend that future research continues to use this assessment method. Research that relates litter condition scores to quantifiable chicken health, welfare and production-related outcomes should also be considered.

Ammonia concentrations during and after litter tilling events can exceed the target value of 15 parts per million (ppm). Growers already use additional ventilation to mitigate the 'spike', but our measurements suggested that even more ventilation was sometimes required. The need for extra ventilation was greater later in the grow-out after more manure had accumulated in the litter. We recommend that growers consider further increasing ventilation during tilling, if safe to do so, and not reducing it for two to six hours after tilling. Some additional ventilation may even be required for twenty-four hours to keep ammonia below 15 ppm, especially in the first evening after tilling. The actual amount of extra ventilation cannot be prescribed as there are many influencing factors. We recommend that growers be made aware of post-tilling ventilation requirements.

OERs were found to increase during tilling, pick-ups and litter clean-out activities. OERs increased by about 20% compared to untilled sheds but returned to normal levels within three hours. We recommend that growers consider this when scheduling tilling or litter cleanout to ensure they undertake these activities at times when they are less likely to contribute to odour impacts. Following the above recommendations for mitigating ammonia concentrations, by managing the timing of tilling and ventilation, will likely mitigate odour risks at the same time.

Many different tilling techniques and practices were used by growers. Their preferences, type and size of machinery, litter conditions (especially moisture and caking), chicken age and liveweight density influenced tilling practices. Some tilling machines did not thoroughly mix litter across the full width of the machine, leaving strips of litter under drinkers that was still quite moist, but friable, after tilling. Growers provided some options to shift wet litter away from under the drinkers, and these were described in relevant fact sheets, but we recommend that research and development be focused on improving the functionality of tilling machines to improve sideways mixing.

Also, regarding tilling operations, there were times when the chickens did not readily move around tilling machinery. We recommend that the industry consider whether chicken behavioural research may provide options for getting chickens to move more easily using ways that are aligned with their instinctive behaviours. Doing so may reduce the risk of injuries, fear and stress and make tilling easier for operators.

Computational models to simulate litter moisture content and drying processes enabled desktop evaluations on a selection of litter management practices. One of the models has been applied in a mobile app by University of Georgia and is freely accessible by Australian growers. The other model is more complex and is currently only suitable for limited RD&E applications. We recommend that the models continue to be developed and expanded to make them more applicable to all of Australia's chicken producing regions and to include more litter management strategies.

Growers will continue to strive to provide chickens with access to dry and friable litter. Fact sheets on topics relating to litter management practice were produced in this project, including case studies of industry-tested solutions. The fact sheets will be hosted on a litter-focused webpage called *Litterpedia*, along with a troubleshooting guide to help readers find information relating to the issue or problem they are searching for. We recommend that AgriFutures Australia provides ongoing support with hosting *Litterpedia* and that the information, fact sheets and other resources be reviewed regularly and updated as necessary in consultation with industry.

Introduction

When this project was conceived, the chicken meat industry had few resources that outlined best management practices (BMPs) for litter management and litter re-use. Formalising BMPs provides a sound basis for training materials and demonstrates to regulators and other stakeholders that high levels of litter conditions are being achieved. The *Best practice litter management manual for Australian meat chicken farms* (McGahan *et al*., 2021) was produced and includes a compilation of litter management practices. This project aimed to expand on the information included in that document by bringing together previous research findings along with practical industry solutions and case studies to serve as an information resource for growers, integrators and industry newcomers. There was a further aim to create a compendium of information about litter management, which has eventually evolved into an online webpage called *Litterpedia*.

During an industry survey, poultry growers described practices being used to achieve high litter standards and to reduce risks associated with poor litter conditions. With such a complex and dynamic production environment that has many variables, it was clear that growers needed a variety of practices that suit their specific situation, rather than a limited number of prescriptive BMPs. While growers have developed and refined practices over many years, research was needed in some areas to improve understanding of the underlying processes associated with the management practices. This was to support refinement of practices, development of new technologies, risk reduction and improved sustainability relating to litter management and chicken meat production.

Many of the management practices already used by poultry growers are aimed at keeping litter as dry as possible. This is because dry litter tends to be friable, which enables the chickens to ‘work’ the litter to break down and incorporate their droppings. Additionally, wet litter is associated with increased ammonia, odour and risks to chicken health and welfare. Water is added to litter by chicken droppings, drinker spillage, water leaks and condensation, and is removed by evaporation. The perceived wetness and deterioration of litter qualities is also affected by the properties of specific litter materials. Previous investigations have focused on understanding the water holding capacity of different litter materials as well as quantifying water additions and evaporation.

In this investigation, we have begun developing a computer-based model to simulate the effects of ventilation, weather and production conditions on litter moisture content. This litter moisture model was applied at two farms during this investigation and underwent limited testing by comparing predicted value to the moisture content of collected litter samples.

Litter tilling, also known as conditioning, stirring or turning, involves the use of machinery to improve litter friability by reducing clumps and caking with a cutting or pulverizing action. It exchanges litter particles at the litter surface and increases surface area and porosity to increase the exchange of water vapour and other gaseous molecules from the litter to the air inside the poultry shed. This aids litter drying but may also increase the concentration of ammonia within the poultry shed. In Australia, poultry growers need to take corrective action if the ammonia concentration exceeds 15 ppm. For short-term increases, such as those occurring during and after litter tilling, growers have found that an effective way to reduce the concentration of ammonia is to increase ventilation. The effects of litter tilling on in-shed ammonia concentrations and the emission rate of ammonia from litter were investigated.

In the past, some development applications for proposed chicken meat farms were hampered by concerns that high odour emission rates (OERs) may occur during routine activities, including litter tilling, pick-ups and shed clean-out. There was an absence of OER data during these events and therefore a need for new OER data to be collected. It was important that industry collect data for these events to quantify emission rates (and enable mitigation strategies to be developed, if necessary) to support new developments and industry growth. Collection of baseline OER data during litter disturbance events was undertaken to support approval of new farms and reduce the risks of odour impacts in the future.

Objectives

The project has the following objectives:

- Develop resources and tools that support growers to use effective practices for managing litter.
- Conduct an industry survey about litter management practices and related challenges experienced by growers. The survey will also include current and potential barriers to re-use of chicken litter and options for overcoming these.
- Develop baseline odour emissions at chicken grow-out farms to support the assessment of new or expanding farm developments. Odour emissions measurements will focus on events including litter conditioning, pick-ups, clean-outs and peak emissions prior to pick-ups.
- Determine the effect of management options such as tilling on bird welfare relating to atmospheric gasses – ammonia (NH_3) and carbon dioxide ($C0_2$).

Report overview

This project addressed a number of RD&E objectives relating to litter, litter management, litter re-use, odour emissions, litter tilling and in-shed air quality (ammonia and carbon dioxide). Many of these topics are inter-related and it was therefore logical to group these objectives together so they may be addressed holistically.

Project activities included undertaking industry consultation, on-farm measurements/experiments, data collection, literature reviews, and producing fact sheets and case studies relating to litter management practices (such as tilling) and litter re-use. The development of fact sheets and case studies on a range of management practices will form a knowledge foundation, supporting industry to continue to provide the best possible environmental conditions in poultry sheds.

Research activities in this project were divided into five streams, with each activity given a chapter in this report:

- Conducting an industry survey of litter management practices and the current and potential barriers to re-use of chicken litter as well as options for overcoming these barriers.
- Investigating litter best management practices (BMPs), including litter re-use, and developing resources and a troubleshooting guide for poultry growers.
- Developing tools or models that assist with quantifying the potential benefits of different practices.
- Evaluating the effect of various litter management practices (including tilling) on bird welfare relating to atmospheric gasses; specifically, ammonia (NH_3) and carbon dioxide (CO_2).
- Measuring odour emissions during events including litter conditioning, pick-ups, clean-outs and peak emissions prior to pick-ups.

Industry survey

Background

Information provided in this section has been adapted from the research paper *An industry survey on litter management and re-use practices of Australian meat chicken growers*, authored by Pepper and Dunlop (2022). This paper is freely available (https://doi.org/10.1071/AN21222). The intent of the paper was to share knowledge of growers' experiences and current opinions on litter management based on the survey data.

Good litter conditions are one of the key requirements in meat chicken rearing to ensure optimal production outcomes. In recent years, expectations for litter conditions have increased, with the minimum standard requiring litter to be of good quality, have minimal risk of being contaminated with toxic agents, and managed to avoid excessive caking, dustiness, wetness or ammonia concentrations that may affect the welfare of the chickens (AHA, 2017; CSIRO, 2002; DAFF, 2022; FREPA, 2020; Gerber *et al.*, 2020; RSPCA Australia, 2020).

To achieve the required litter conditions, Australian meat chicken growers have been refining their litter, ventilation and drinker management practices. Some Australian meat chicken growers perform mechanical litter tilling (otherwise known as litter turning, stirring or conditioning) during the grow-out period to break up cake and maintain litter in a friable state. Litter tilling may be defined as 'using machinery to break up caked litter, reduce the size of litter clumps with a cutting or pulverising action, mix wet with drier litter, and redistribute it at the back of the machine in a friable and homogenous surface layer'. Tilling creates favourable litter conditions by simultaneously reducing dust levels and minimising peak moisture content. This in turn reduces susceptibility to caking.

In addition to managing litter during the grow-out, there has also been increasing interest in re-using litter for multiple grow-outs (Cockerill *et al.*, 2020), as opposed to using new bedding for every growth cycle (McGahan *et al.*, 2021). There has also been interest in sourcing alternative bedding materials because of localised shortages in supplies of traditional bedding materials (wood shavings, sawdust, rice hulls and straw) due to events including bushfires and drought (Watson and Wiedemann, 2019).

In this investigation, meat chicken farm owners, managers and staff (collectively known as 'growers') and poultry integrator company representatives were surveyed about their experiences regarding litter management practices and re-use. This was to gain a deeper understanding and improve the focus of research, development and extension activities (RD&E) on these topics. Industry surveys are very useful for informing researchers, policy makers and other stakeholders about industry-specific practices. A similar survey was undertaken in France by the Chambre d'Agriculture de Bretagne (The Chamber of Agriculture, Brittany), which gathered information about their poultry growers' litter management practices, to understand the progression of these practices over the years, and to identify ways for researchers and extension staff to better assist their farmers (Dezat and Gohier-Austerlitz, 2000).

These survey results will be utilised in future RD&E activities to ensure research is informed by current industry practices, especially odour, ammonia and carbon dioxide measurements during litter tilling and other litter disturbance events. The survey results will aid in prioritising case studies that demonstrate industry-proven management practices concerning litter.

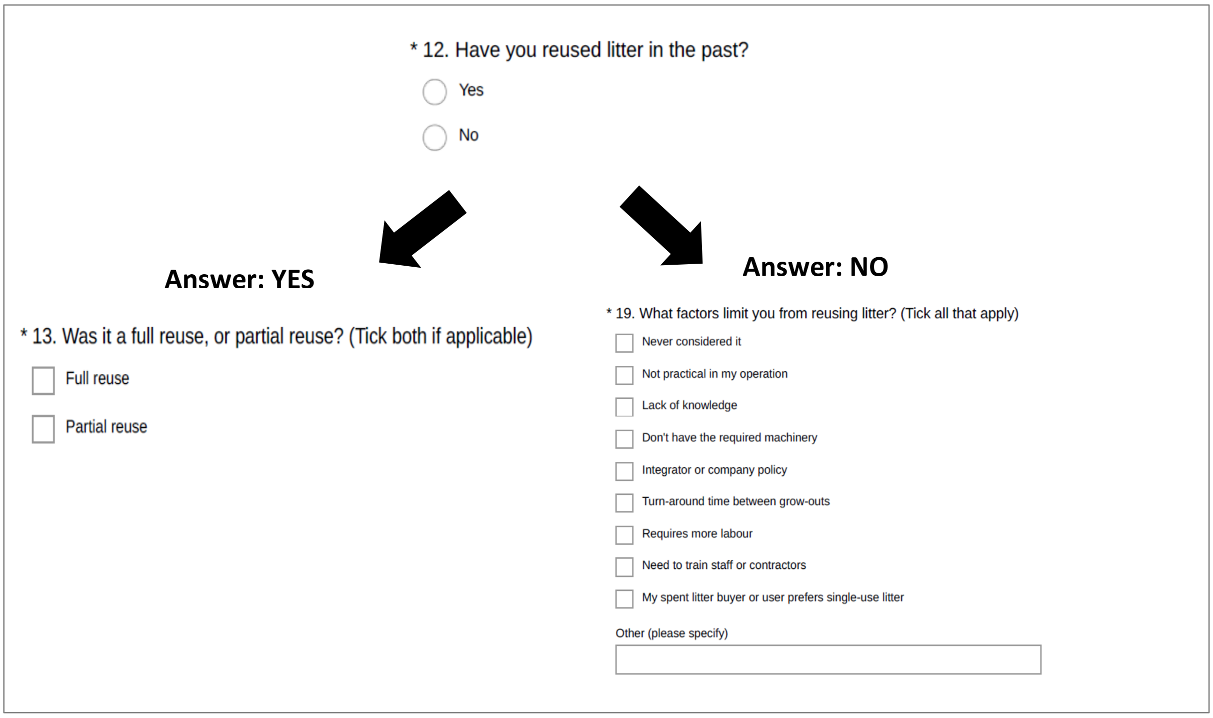
Objectives

Litter management is important when rearing meat chickens because litter conditions can affect production as well as chicken health and wellbeing. The objective of conducting this industry survey was to gather information from Australian meat chicken growers and integrators about their litter management practices, providing an opportunity to share their knowledge, experiences and perceptions about litter re-use and litter tilling. This information was essential for this project because it provided a better understanding of litter preparation, timing of litter management practices and shed/ventilation configuration to ensure that representative data could be collected.

Another objective was to identify key topics that growers want further resources and information on. The steering committee assisted with prioritising these topics. The intention was to develop fact sheets, procedures and other informational resources.

Methods

The *Litter Management Survey* (Appendix 1) was an online survey consisting of 37 questions with a variety of open ended, multiple choice and ranking scale questions. Some questions were grouped, and respondents were directed through different paths in the survey based on one or multiple answers given (Figure 1). This enabled the project team to focus questions on specific topics, depending on how they answered the previous questions. It avoided the need for respondents to answer questions about specific topics (for example, litter re-use) if they answered an earlier question stating that they had no experience with the practice.



* 12. Have you reused litter in the past?

○ Yes

○ No

* 13. Was it a full reuse, or partial reuse? (Tick both if applicable)

☐ Full reuse

☐ Partial reuse

* 19. What factors limit you from reusing litter? (Tick all that apply)

☐ Never considered it

☐ Not practical in my operation

☐ Lack of knowledge

☐ Don't have the required machinery

☐ Integrator or company policy

☐ Turn-around time between grow-outs

☐ Requires more labour

☐ Need to train staff or contractors

☐ My spent litter buyer or user prefers single-use litter

Other (please specify)

Figure 1. 'Skip logic' feature used in the survey, enabling questions to be automatically skipped if not relevant

The survey was distributed to growers and integrators staff via industry representatives and grower networks, with all responses collected anonymously. The provision of contact details was voluntary.

The survey had three sections:

1. Farm location and characteristics
2. Litter re-use
3. Litter management, with a focus on litter tilling.

Results and discussion

Overall, a total of 84 responses were received from six states, with 98% from growers and 2% from integrator representatives.

Farm location and characteristics

Farm location – growing regions

Information about farm location and characteristics were collected to improve our understanding about the possible effects of farm location, size and shed design on litter management strategies. Regional differences were anticipated relating to climate and litter supplies, which could affect litter management practices, and allowed investigation of individual responses to reflect national or region-specific experiences and trends. These regions were North Queensland, South East Queensland, New South Wales Central Coast, inland New South Wales, southern coastal Victoria, inland Victoria, Western Australia, South Australia and Tasmania (Figure 2).

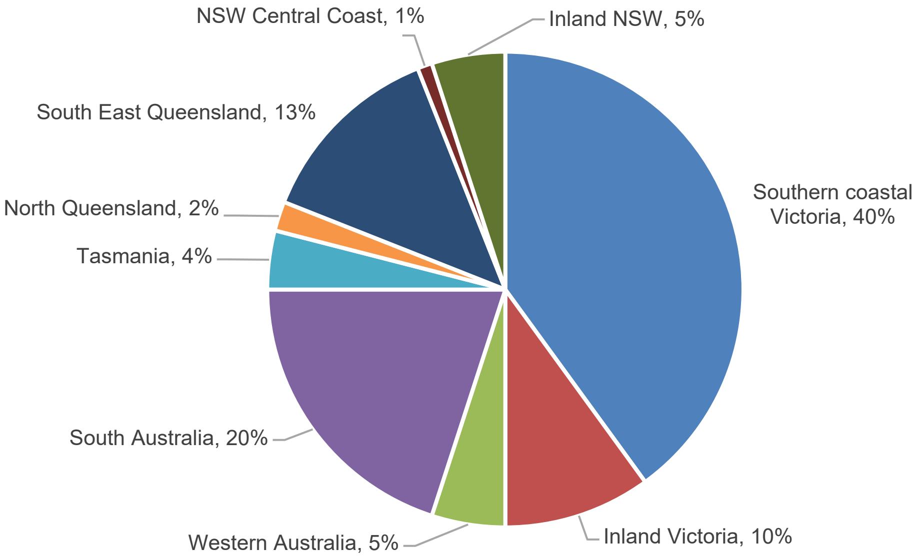


Figure 2. Distribution of survey responses from different regions.

The most responses were received from the southern coast of Victoria, while the least were received from the New South Wales Central Coast, potentially reflecting the number of growers and meat chicken farms in those regions (Figure 2). The nation-wide responses received provided an insight to practices across the whole of the chicken meat industry.

Combining regions for data analysis

When the survey data was analysed, small response numbers in some regions required the responses to be pooled with other regions (Table 1) to analyse and gain the best results out of the data. Once grouped, the data was able to be analysed through statistical analyses such as regression analysis, chi-square, fishers' test and others that were considered appropriate. These tests were performed to gain the best representation and understanding of the data as well as to demonstrate any significant differences between the results.

Table 1. Distribution of survey responses from different regions. Shading indicates regions with similar climates.

Regions	Number of responses	Combined regions for data analysis
North Queensland	2	14
South East Queensland	11	
NSW Central Coast (e.g. Hunter Valley, Mangrove Mountain, Goulburn)	1	
Inland NSW (e.g. Griffith, Tamworth)	4	12
Inland Victoria (e.g. Bendigo)	8	
Southern coastal Victoria (e.g. Geelong, Mornington Peninsula)	34	37
Tasmania	3	
Western Australia	4	21
South Australia	17	
Total number of responses	84	

Farm size and production systems

The survey showed that there was a relatively even distribution of different farm sizes ranging from 20,000–100,000 chickens to farms with more than 400,000 chickens (Figure 3). The responses showed that South Australia and inland New South Wales have a greater proportion of >400,000 capacity farms, whereas Tasmania and the New South Wales Central Coast have a greater proportion of <100,000 capacity farms.

Furthermore, conventional farms were the most common type of farm, followed by free-range farms. Some respondents had both conventional and free-range production systems, with the southern coast region of Victoria responding with the most free-range farms.

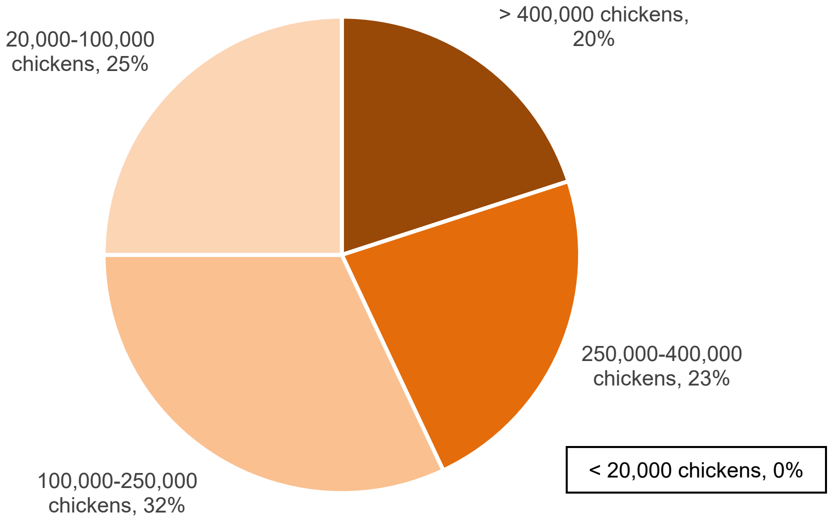


Figure 3. Distribution of farms stocking capacities (n=84).

Building design, construction, ventilation and environmental control equipment

Each respondent's building design was expected to influence their management practices and the challenges they experience. Most farms had tunnel ventilated sheds, while others had cross ventilation or natural ventilation. Some respondents indicated that they have a combination of multiple ventilation types (Figure 4). Nearly a quarter of farms had in-shed air circulation or destratification fans. Some growers located in the southern coast region of Victoria reported having both tunnel and cross-ventilation in their sheds.

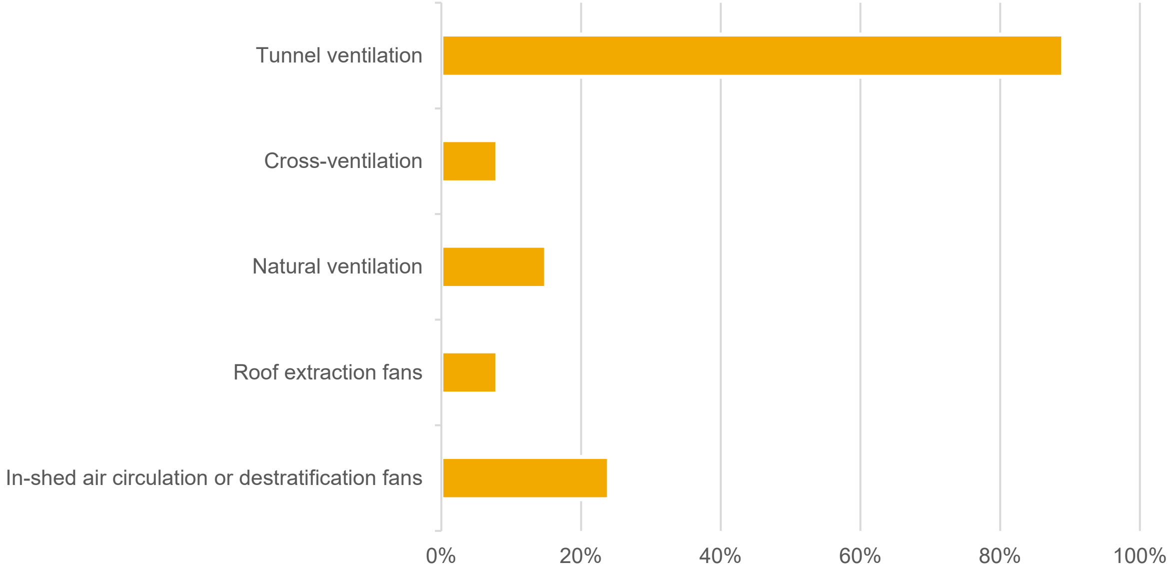


Figure 4. Type of ventilation used in meat chicken sheds (n=84). Note: Respondents could provide multiple answers.

Regarding the type of heaters used within a shed, most respondents had hot air/forced air/space heaters, with a small number of respondents using brooder or tube/radiant heaters (Table 2).

Table 2. Types of heaters used in sheds. Note: Respondents could provide multiple answers.

Types of heaters used on farms	Responses	
Hot air/forced air/space heaters	94%	79
Small brood heaters	4%	3
Tube/radiant heaters	6%	5
Underfloor heating	0%	0
Hot water/radiator/fin tube heaters	1%	1
Electric heaters	1%	1
Other (please specify)	0%	0
Total number of respondents		84

Respondents had the following building design elements in their sheds (Figure 5):

- Insulated solid walls were more common than curtain or concrete walls.
- More than half of the respondents use plastic mini vents rather than metal mini vents.
- Tilt panel tunnel inlets were more common than curtain tunnel inlets.
- More than half have exposed purlins in their sheds and nearly half have exposed roof trusses.
- Compacted earth floors were the main floor type, with a small proportion of respondents using concrete floors. Another type of shed floor reported was cement-treated road base.

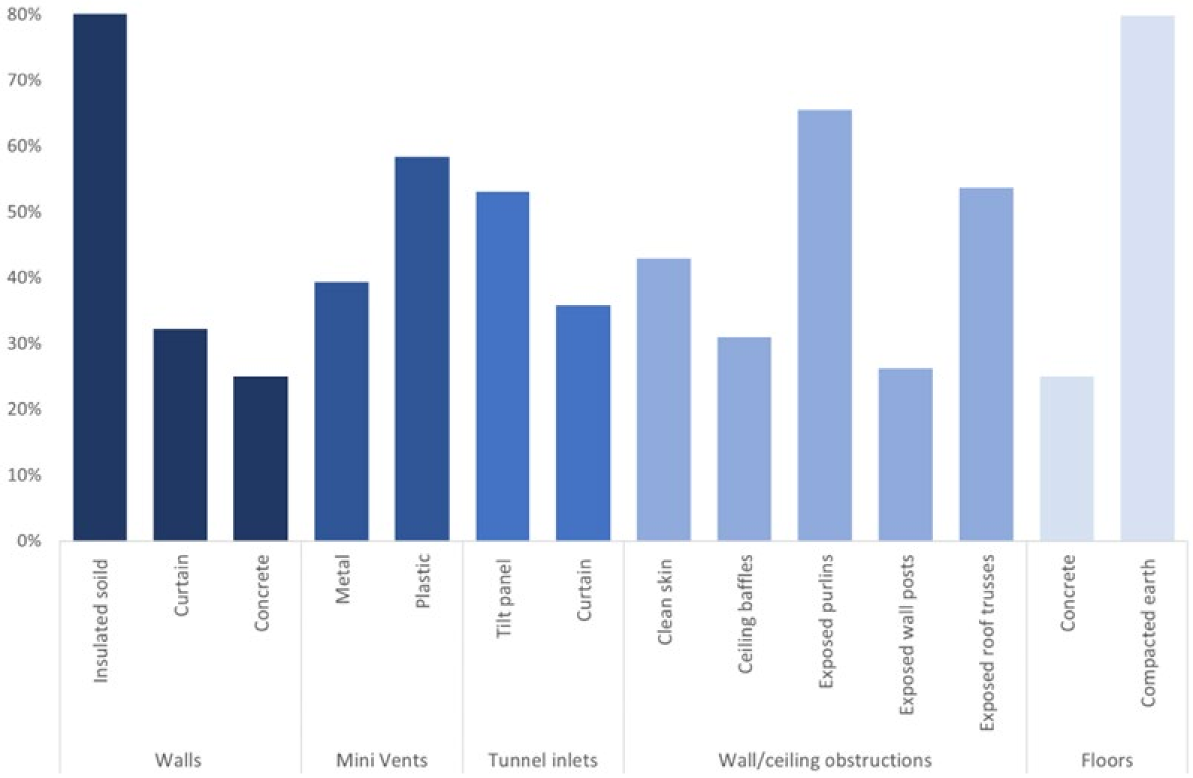


Figure 5. Shed building designs elements including wall and floor type.

Take home messages – shed characteristics and heating

Most growers have tunnel-ventilated sheds and use area/space heaters. Some growers also have less common ventilation equipment such as circulation fans and/or roof extraction fans. BMPs and industry training should consider different combinations of ventilation systems to highlight potential benefits or challenges that these may have for growers.

Regular and alternative bedding materials

The most common type of bedding material used was softwood shavings, followed by hardwood shavings (Figure 6). Straw was the primary bedding material used in South Australia, but was also used in inland New South Wales, Victoria and Western Australia. Paper and peanut shells have been identified as an uncommon type of bedding material; however, may be considered as an alternative material. Alternative bedding materials refer to those that are not a grower's first preference/primary option, perhaps due to supply difficulties or price.

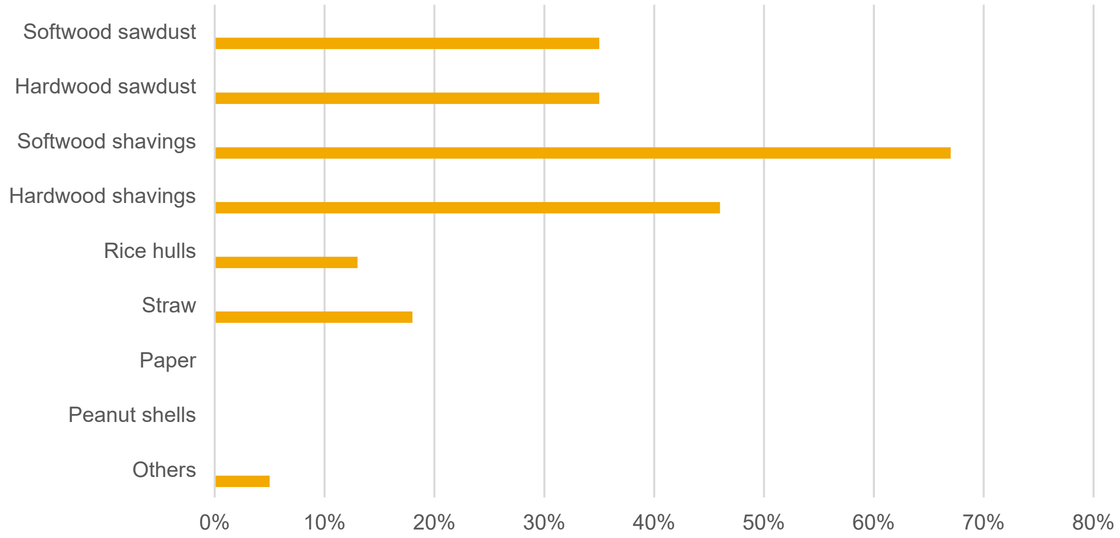


Figure 6. Distribution of different types of bedding materials being used (n=84). Note: Respondents could provide multiple answers.

Despite some bedding material shortages in recent years due to external influences such as drought and bushfires, only a few respondents stated that they regularly need to source alternative materials for their operation (Figure 7). Sourcing alternative bedding materials was applicable to less than half the respondents; however, those who used rice hulls (13%, primarily located in the inland New South Wales region) commented that they were having difficulty sourcing the material. Other material types that respondents have used when supplies were limited included almond hulls, wood chips and re-used litter.

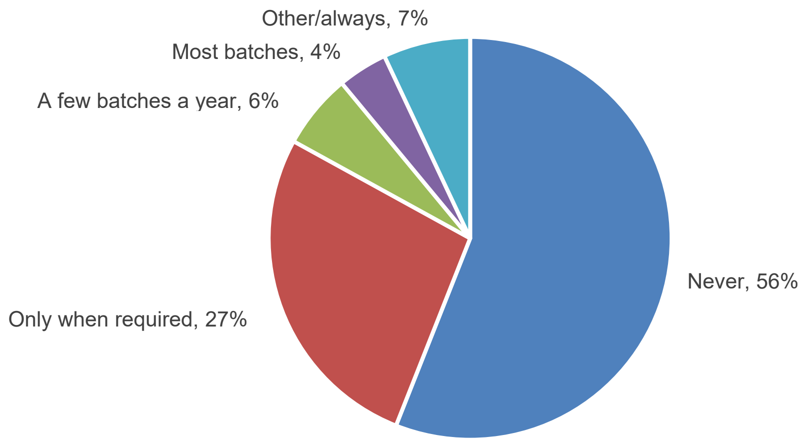


Figure 7. How often growers/integrators need to use alternative bedding materials (n=84).

As a result of bedding material supply constraints, more than half of growers would consider re-using litter to assist with prospective supply difficulties, while the remainder indicated they would never re-use litter (Table 3).

Table 3. Consideration of re-using litter when litter sources become difficult.

Would you consider re-using litter if your normal litter sources became difficult and/or as an alternative practice?	Responses	
Yes	58%	49
No	42%	35
Total responses		84

Take home messages – bedding materials and re-use

BMPs and industry training need to take into consideration the use of different bedding materials and their impact on litter management practices, because there are regional trends in the type of bedding materials that are available and commonly used. For example, straw is commonly used in South Australia and rice hulls are used in New South Wales. Nearly 60% of growers would consider re-using litter.

Experiences with litter re-use

Many participants have never re-used litter in the past (Table 4). Out of the 32% who have, most have practiced partial re-use, with only a small proportion having experience with full re-use of litter. Partial re-use involves using new bedding in the brooding section and the re-used litter in the other non-brooding areas of the shed. In comparison, full re-use involves re-used litter being used throughout the entire shed. About half of the growers who have re-used litter only did so when required, while the rest were regular re-users.

Table 4. Litter re-use experience, including whether partial or full re-use.

Have you re-used litter?	Responses	
Yes	32%	27
If yes – full re-use (32% of yes responses)[#]		
If yes – partial re-use (81% of yes responses)[#]		
No	68%	57
Total responses		84

[#] four growers had re-used previously with both partial and full re-use

For those who responded “no”, they were asked which factors limit them from reusing litter. The main factor limiting respondents was integrator or company policy, followed by the turn-around time between grow-outs (Figure 8).

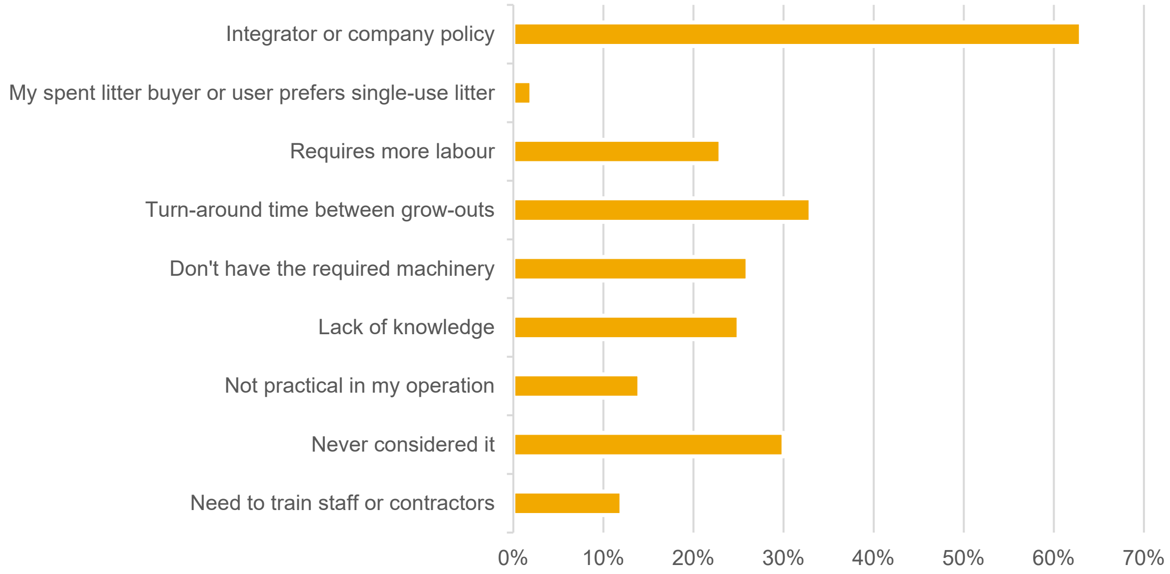


Figure 8. Factors limiting the uptake of litter re-use as a management practice. Note: Respondents could provide multiple answers.

The other dominant responses received around the limitations to re-using litter had similar themes:

- Lacking knowledge and/or the need to train staff – 37%
- Lacking the required machinery and labour – 49%
- Integrator policy or insufficient time between grow-outs due to placement scheduling – 96%
- Some respondents have never considered re-using litter – 30%.

There is an opportunity for an education and training program to support uptake of litter re-use where required due to operational or bedding supply issues, especially with the growers who had simply never considered re-using litter or said that they lacked the knowledge or experience to confidently start re-using litter or training their staff to do so.

South East Queensland had the highest rate of litter re-use, with all growers responding that they have re-used litter and 80% re-using litter during at least 3–4 grow-outs per year (Table 5). South Australia had the second-highest rate of re-using litter (with 35% of the growers having re-use experience), but these growers only re-used litter when required.

Table 5. Regional summary of litter re-use frequency (based on data from respondents who re-used litter, n=27).

Region distribution of litter re-use	Inland NSW and VIC	QLD and NSW coast	SA and WA	VIC coast and TAS
Never	32	2	15	8
1-2 flocks per year	0	0	1	0
3-4 flocks per year	1	3	0	0
All flocks	1	6	0	0
Only as required	2	3	6	5

The most influential factors for re-using litter were the integrator or company policy (Figure 9) followed by the availability and cost of new bedding. Some provided additional comments describing their high level of concerns about higher ammonia concentrations, and one grower indicated that their previous litter re-use experience was only for trial purposes.

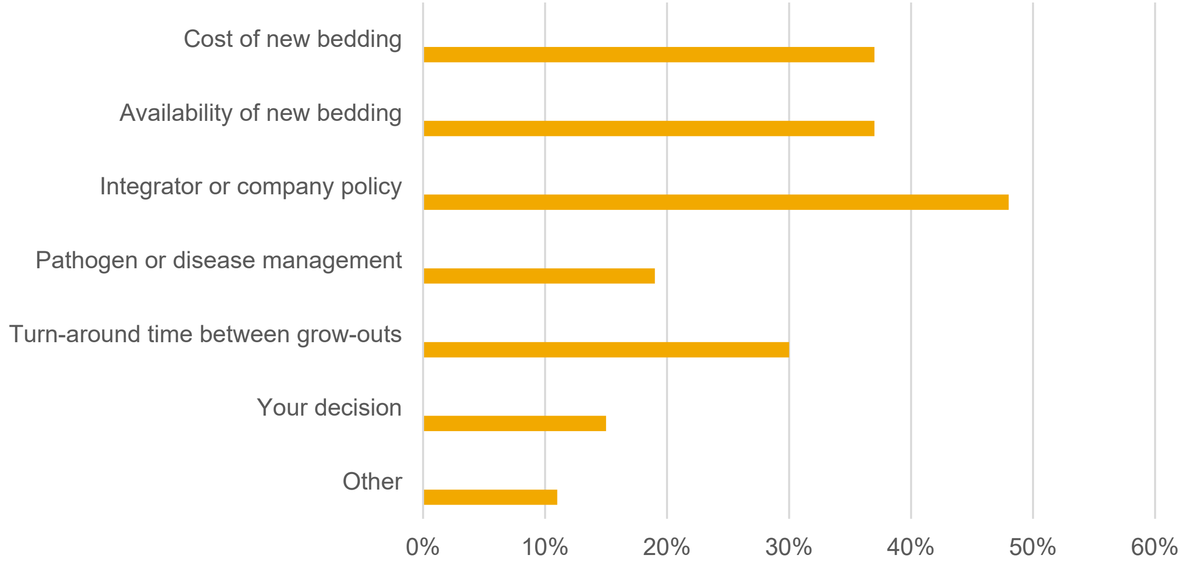


Figure 9. Factors influencing the decision of practicing litter re-use (for those who re-use litter, n=27 respondents). Note: Respondents could provide multiple answers.

Techniques used for reliable, safe and dependable litter re-use

Growers who re-use litter have developed and refined their practices to ensure they have safe, reliable and repeatable outcomes from re-using litter. The aim is to release water and ammonia and to reduce pathogen loads before the next grow-out starts. The most common practice to ensure litter re-use was successful was by windrowing or heaping litter between batches (Table 6). Spreading and drying re-used litter before batches was also practiced, with some respondents commenting that they allow at least 2–4 days (the longer the better) after breaking down heaps or windrows for the re-used litter to dry and release ammonia before day-old chicks are placed in the brooding section.

Subsequent discussions with growers provided additional details, including the need to till the litter 5–6 times before setting up the shed for the next batch to ensure that as much water and ammonia was released as possible.

Common practices used during the grow-out included using extra ventilation and using a brood curtain with ventilation configured to draw ammonia and any other aerial contaminants away from the brood area. Additional details provided by growers described that they achieve this by latching closed side-wall vents in the non-brooding section and operating a fan at the end of the shed furthest from brooding.

Table 6. Techniques practiced to ensuring litter re-use is successful.

Management practice used to ensure success of litter re-use	Responses	
De-caking or removing wet or heavily soiled litter	38%	10
Windrowing or heaping between batches	70%	19
Spreading and drying before placing chicks	37%	10
Extra pre-heating	11%	3
Using a brood curtain with ventilation away from the brood	52%	14
Extra ventilation during brooding	56%	15
Using sensors to monitor ammonia concentration in the brooder section	30%	8
Other (responses provided in comments):		
- Extra ventilation in re-used litter area and place chicks on fresh bedding	22%	6
- Allowing extra time to spread out and dry litter- longer the better		
Total number of responses (only those who have re-used litter)	53 responses from 27 respondents	

Benefits vs challenges found when reusing litter

Most growers who re-used litter explained that the biggest benefits were the reduction in bedding costs and having increased litter depth (Figure 10), which contributes to better insulation and warmth in the shed, especially during brooding. Only a small proportion of respondents found no benefits. The greatest challenge experienced by participants was the risk of increased ammonia levels, which is likely related to concerns for work health and safety, which also received a strong response (Figure 11). Some growers also reported challenges with controlling darkling beetles, increased dust and the requirement for additional labour.

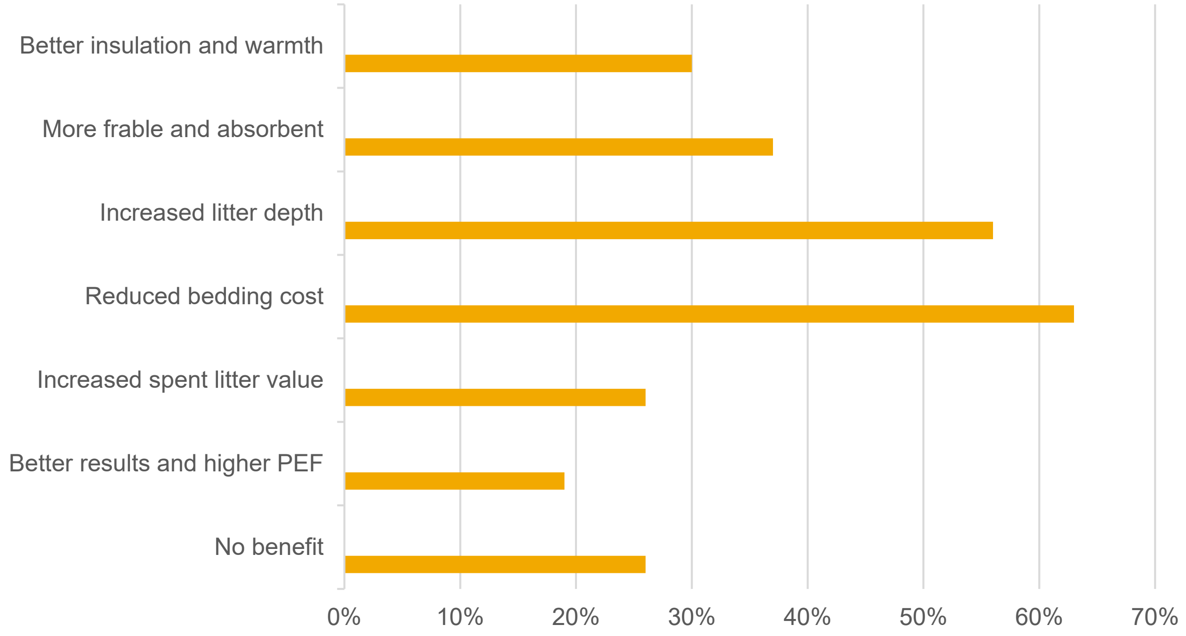


Figure 10. Benefits experienced with re-used litter (n=27 respondents) (PEF = production efficiency factor). Note: Respondents could provide multiple answers.

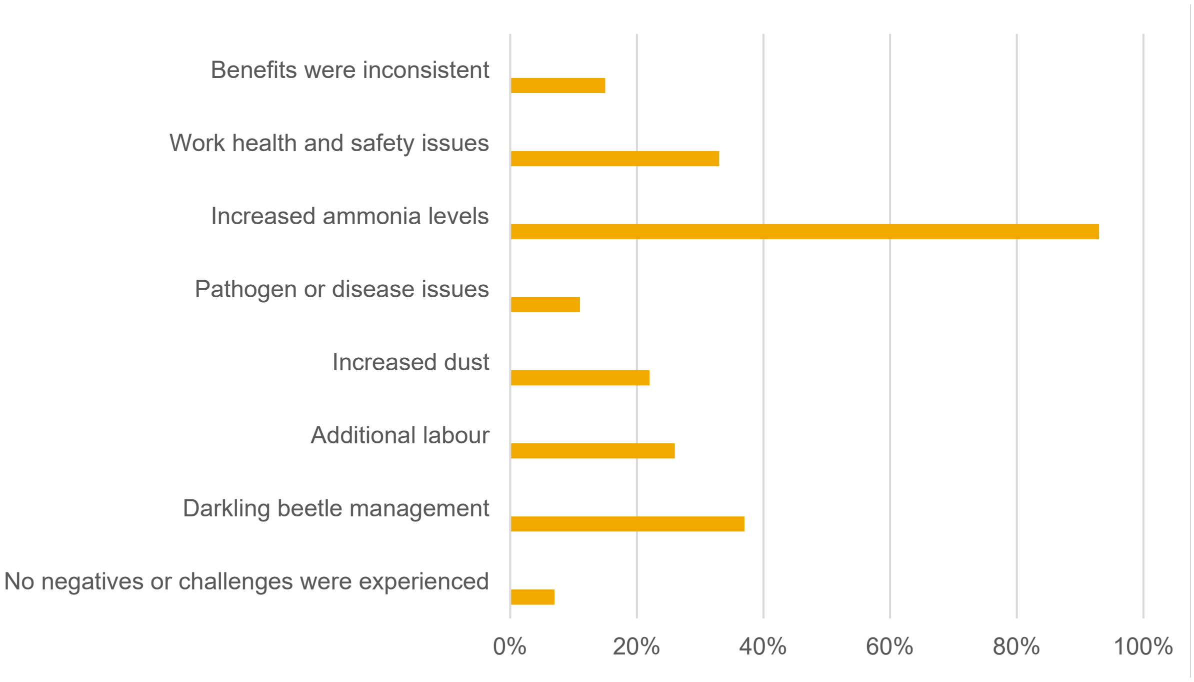


Figure 11. Challenges experienced with re-used litter (n=27 respondents). Note: Respondents could provide multiple answers.

Survey respondents were asked to describe their level of concern about some potential issues relating to litter re-use (Figure 12). Many respondents indicated that they were extremely concerned about increased ammonia concentration, followed by concerns about increased odour. Integrator requirements, worker safety, short turn-around times, increased risk of disease and increase presence of pathogens were other leading concerns.

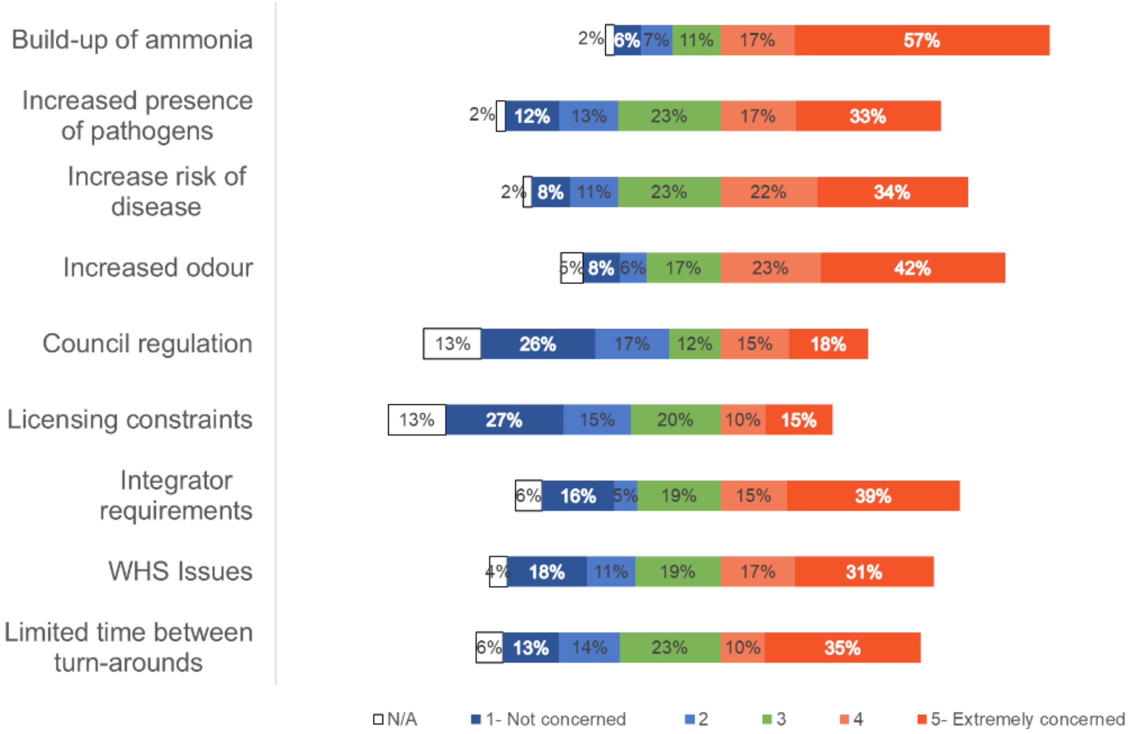


Figure 12. The level of concerns for issues relating to re-used litter (n=84).

Other comments and points raised about litter re-use included:

- Turnarounds are too short and inconsistent (10%)
- Knowledge required of the best operational practices when reusing litter (5%)
- Difficulty complying with regulations and standards such as RSPCA (23%)
- Concern for disease (5%)
- Lack of knowledge and negative perception of the practice (14%)
- Litter re-use could affect footpad and hock burn scoring (5%).

Take home messages – litter re-use

Growers reported that re-using litter was cost effective and had other benefits relating to litter properties and litter management. However, there were some challenges relating to ammonia, litter beetles, resourcing (machinery, labour) and staff training.

Despite only 32% of growers having any experience with litter re-use, nearly 60% were prepared to consider the practice. Therefore, BMPs and industry training should focus on litter re-use to support growers successfully adopt this practice at their discretion.

Perceptions and concerns were raised about litter re-use including ammonia concentrations affecting bird health, odour, disease and pest risks, integrator requirements, council and licencing requirements, and turn-around times.

Litter tilling and other practices for maintaining friable litter

Out of the 84 respondents, 89% indicated they use litter tilling and 9% stated they only use ‘other’ management practices. A greater proportion of conventional farms reported that they practice litter tilling than free range farms. Respondents who practice litter tilling were then asked additional questions about the types of machinery used, the triggers for a litter tilling practice, cake occurrence, time relative factors and more.

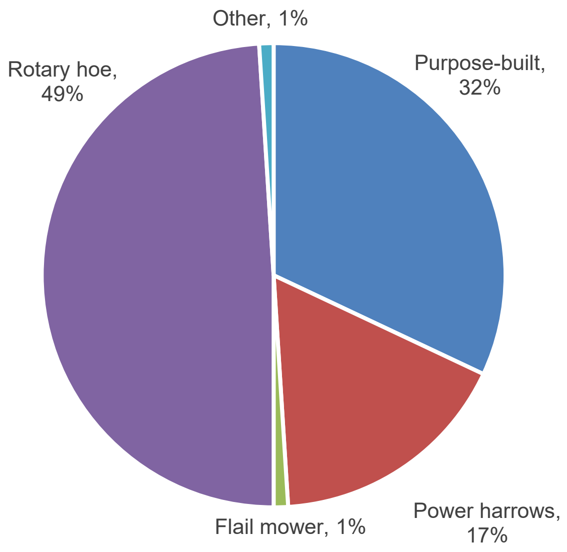
Litter management practices to maintain friable litter

Management practices used to manage litter and achieve dry and friable conditions included:

- Ensuring adequate ventilation
- Monitoring and managing humidity in the shed
- Using circulation fans
- Top-dressing with new, dry bedding, which may or may not include removing the wet litter
- Hand ranking or using a small mechanical rotary hoe to break up caked or susceptible areas, e.g. under drinker lines
- Tilling the whole shed with tractor-powered implements
- Monitoring and maintaining effective drinker heights and pressure.

Machinery used for litter tilling

The most common type of machinery used to conduct litter tilling was a rotary hoe, followed by purpose-built litter tilling implements and then power harrows (Figure 13). Relating to size, most of these were small tractors (up to 1.5–1.8 metres wide), followed by larger tractors (wider than 1.5–1.8 metres) or walk-behind machines (Figure 14).



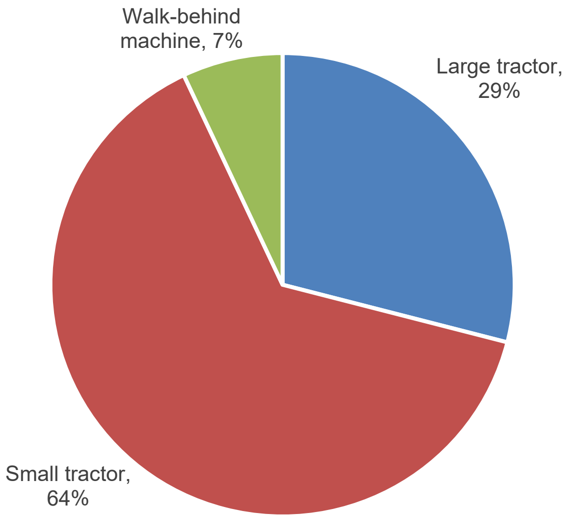


Figure 13. The type of litter tilling machinery used (n=74).

Figure 14. Sizes of the litter tilling machinery (n=74).

Frequency, scheduling and duration of litter tilling

Growers were asked if they performed litter tilling on a scheduled, regular basis or in response to caking. Over half (55%) responded that they perform litter tilling in response to caking and the remainder responded that it is a scheduled, regular activity (45%). A few additional comments were also provided including:

- In response to wet litter
- Prior to caking
- Before an inspection.

For those who scheduled tilling, the most common frequency was weekly (64%). The majority of growers till litter in the mid-morning (80%) and some reported tilling around noon (46%).

Growers reported that tilling takes an average of 30 minutes to one hour (52%) per shed, but some responded that it takes longer (1–2 hours, 40%). The length of time taken to till the litter in the shed was influenced by the size of machinery (Figure 15). Those who used a walk-behind machine (n=5) reportedly took 12 hours and only one respondent reported taking more than two hours per shed. Most growers with a small tractor (n=48) took 30 minutes to two hours per shed. Growers with a large machine (n=22) all took less than two hours, with the majority (68%) taking 30–60 minutes.

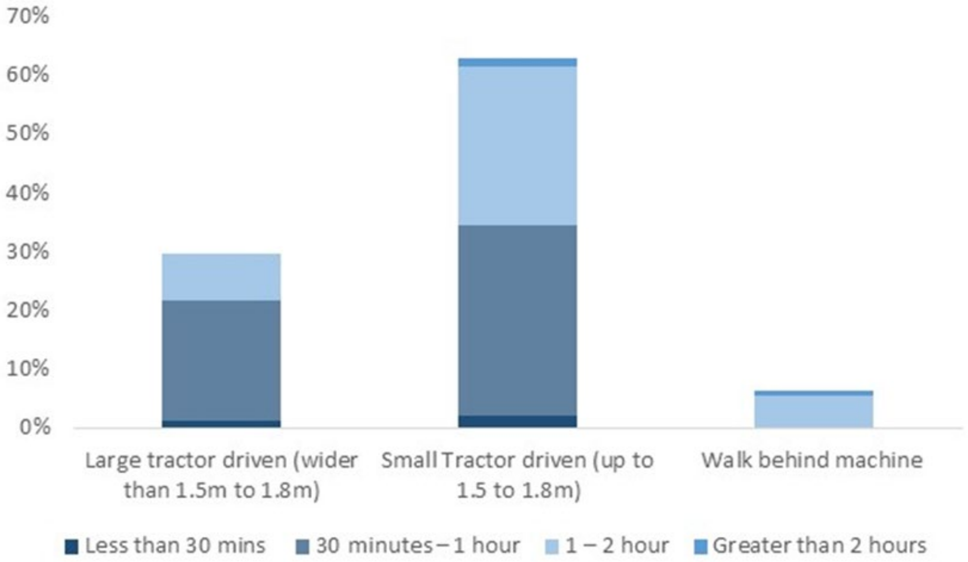


Figure 15. Time taken to complete litter tilling a shed for different sized machines.

Perceived concerns and limitations with litter tilling

The survey showed that there were times of the grow-out when growers were either unable or unwilling to till the litter. The main reason was concern for chicken welfare, especially while operating machinery in the shed when the chickens were very young or when the shed had high density. The density of chickens in the shed (kg liveweight per m² floor area) increases as the chickens grow. It usually peaks before the small-bird thin-out on day 31-35 and again before the large bird pick-up at the end of the grow-out (ranges between day 50 and 56).

The periods of highest concern were days 1 to 7, days 27–34 and days 48–58 (Figure 16). Trends were observed between the size of machinery and the days when growers reported being unable to perform tilling. Growers with small tractor-mounted machinery (64%) and larger machinery (30%) said that they were less able to till on day 27–34 than those with walk-behind machines. Some growers said they would be able to till on any day of the grow-out.

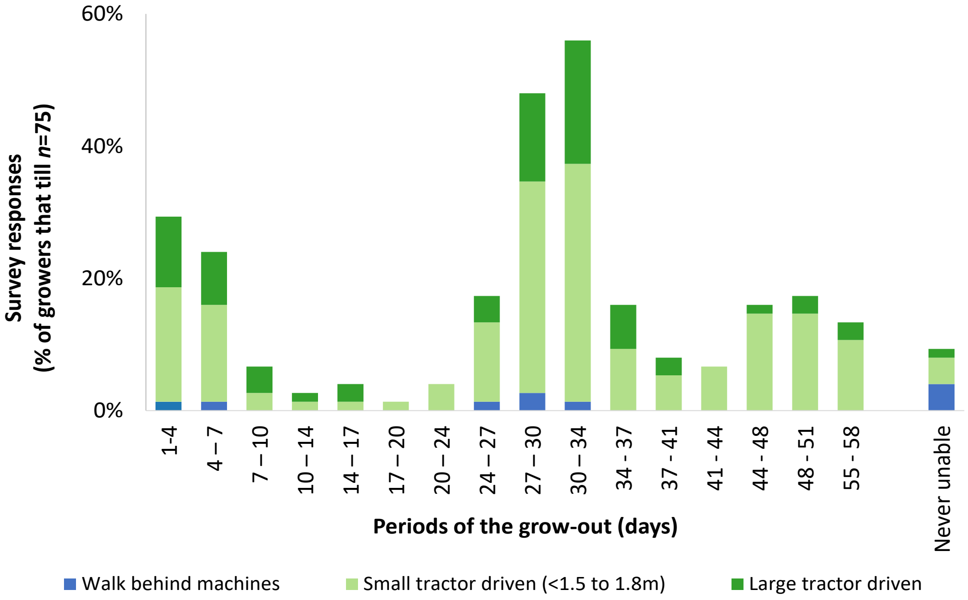


Figure 16. Days of the grow-out when growers reported that they are unable to till the litter, categorised by the size of their tilling machinery.

Locations in the shed that litter tilling occurs

Most respondents indicated that caking occurs mostly under drinker lines (84%) but even so, most respondents prefer to till the entire shed floor (Figure 17). Other litter tilling strategies provided by respondents included:

- Focus efforts under the drinker lines
- Using a walk-behind tilling machine to target specific areas, sometime between whole-shed tilling events
- Preventative tilling before caking
- Tilling the pick-up area after pick-up is completed, while that section of the shed is still empty and free of obstructions
- Targeting cool cell end only if the quality in the rest of the shed is acceptable
- Tilling across the most susceptible areas to mix wet and dry litter together.

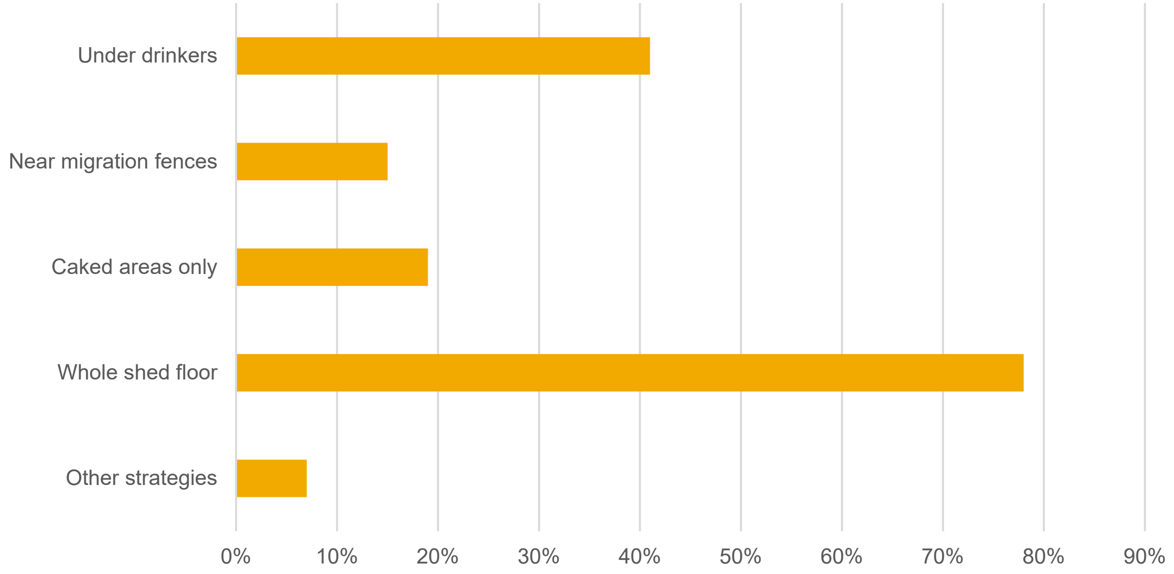


Figure 17. Areas within a shed that are the primary focus of tilling activities. Note: Respondents could provide multiple answers.

Additional comments on the management of litter

Additional comments were provided about strategies used by growers to keep litter friable, including:

- Using circulation fans
- Appropriate and effective ventilation
- Regularly adjusting drinker height and performance maintenance
- Hand raking or using a small rotary hoe to target specific areas, e.g. under drinker lines
- Top-dressing: removing wet litter and replacing with fresh material

- Correctly using migration barriers to prevent density at a particular area of the shed
- Managing and monitoring humidity within the shed
- Maintaining the quality of sheds and keeping equipment in good condition

Growers also commented that having good-quality feed was essential for managing litter conditions

Take home messages – litter tilling

Litter tilling is widely practised.

Growers suggested that larger equipment is more effective for maintaining friable litter than small, walk behind machines, and is also quicker. Walk-behind machines still have their uses, including being able to till without needing to lift drinker and feeder lines, and being able to till the litter on more days of the grow-out.

Bird density during litter tilling is the greatest concern expressed by growers. This relates to the potential impact the equipment could have on the welfare of the birds. Many growers indicated that they are unable and unwilling to till litter at the start of a grow out, and just before pick-ups, when bird density is highest (1-7 days, 27-35 days, and after day 44).

Growers were also concerned about ammonia concentrations during and after litter tilling.

BMPs and industry training need to prioritise ventilation, heater, animal husbandry and drinker management practices before focusing on litter tilling techniques. Litter tilling is a complimentary practice to these and not the leading solution.

Implications and recommendations from the industry survey

This industry survey has captured a snapshot of how meat chicken growers across Australia currently manage litter, with a focus on litter re-use and litter tilling. Eighty-four survey responses were received from all major growing regions across Australia, representing free-range and conventional production systems. The survey showed that litter re-use is limited, but litter tilling is a widespread practice. Litter tilling is used to reduce the occurrence of caked litter and to keep litter ‘working’ so that fresh excreta can be incorporated into the litter by chicken activity.

Comments from the survey indicated that litter tilling alone does not achieve dry and friable litter, and that proactive ventilation, heater and drinker management are essential. Growers also explained that litter tilling is not without its challenges, and can potentially contribute to spikes of dust, ammonia and/or odour, as well as being potentially risky to carry out when there is high live-weight density.

The growers’ comments and responses were used in producing resources and information to support their management. A survey like this hadn’t been conducted in Australia before and it provided valuable understanding of the challenges that growers have faced as well as where research, development and extension was required to support existing practices or encourage uptake of improved practices if needed.

Fact sheets, case studies and Litterpedia

Background

The *Best practice litter management manual for Australian meat chicken farms* (McGahan *et al.*, 2021) is a compilation of litter management practices. Plans were made for the document to be converted into a web page to increase accessibility for growers and stakeholders, and to add a search function so that users could quickly find the information that they were after.

Using feedback and topics highlighted in the industry survey, priority topics were identified where more detailed information was needed. Following grower and industry consultation, a decision was made to produce fact sheets and case studies that could communicate practical information on these topics. An internet-based webpage called *Litterpedia* was created to be a compendium of any information relating to litter, starting with information that was already published in the litter management manual, but also linking to new information, such as the fact sheets and case studies that were created during this project.

The term 'best management practice' is widely used. Commercially rearing meat chickens is a very complex activity, and there are many variables between farms, seasonally and regionally. It must be stated that **there is no single best practice**, and that growers need to have a variety of practices and tools available so that they can choose the most appropriate one for their situation. It was hoped that the fact sheets and case studies created during this project would provide practical information about a range of practices, for the benefit of both experienced growers and newcomers to the industry.

Objectives

The objectives of this part of the project were:

- Compile, prepare and publish information to complement and enhance the information in the *Best practice litter management manual for Australian meat chicken farms.*
- Prepare case studies of good practices currently used by growers.
- Support the litter management information provided by growers with science-based principles (when relevant) to discuss the underlying fundamental processes.
- Develop resources that are ready to host on the *Litterpedia* webpage.

Results and discussion

Litterpedia has been created as a compendium of information relating to litter management. At the time of writing this report, it was a live website (but under construction) that will be a long-term solution for hosting contemporary information about litter management. A list of priority headings, 'tags' and information topics were prepared along with supporting fact sheets and resources.

A troubleshooting guide was also conceived to link growers and stakeholders to resources and information relating to problems or issues that they are experiencing (Appendix 2 shows the main categories included in the troubleshooting guide). With the assistance of web managers, guidelines were developed about who will upload information and what quality checks and approvals were required before information was uploaded.

Fact sheets and case studies were developed to focus on the following topics: (1) drinker management; (2) keeping litter dry and 'working', including reducing risks associated with ammonia; (3) ventilation; and (4) litter condition assessment. All were reviewed and approved by an industry committee.

Drinker management

This topic consisted of four fact sheets, three procedures and two case studies (Figure 18). Drinker management was viewed as one of the leading practices for managing litter moisture. The litter underneath drinkers is frequently wetter than the rest of the shed and is often where surface caking starts to form. There are many reasons for more water being added to the litter underneath drinkers, including water leaks or spillage while chickens are drinking. Having clean, well-maintained and properly adjusted drinkers will reduce the amount of excess water being added to the litter by the drinkers. The fact sheets provided practical information about how to assess, adjust and clean drinker lines, including how to identify when drinkers are worn or damaged and need replacement. The fact sheets also provided information on using medium flow drinkers, which some growers have found useful in preventing excessively wet litter.

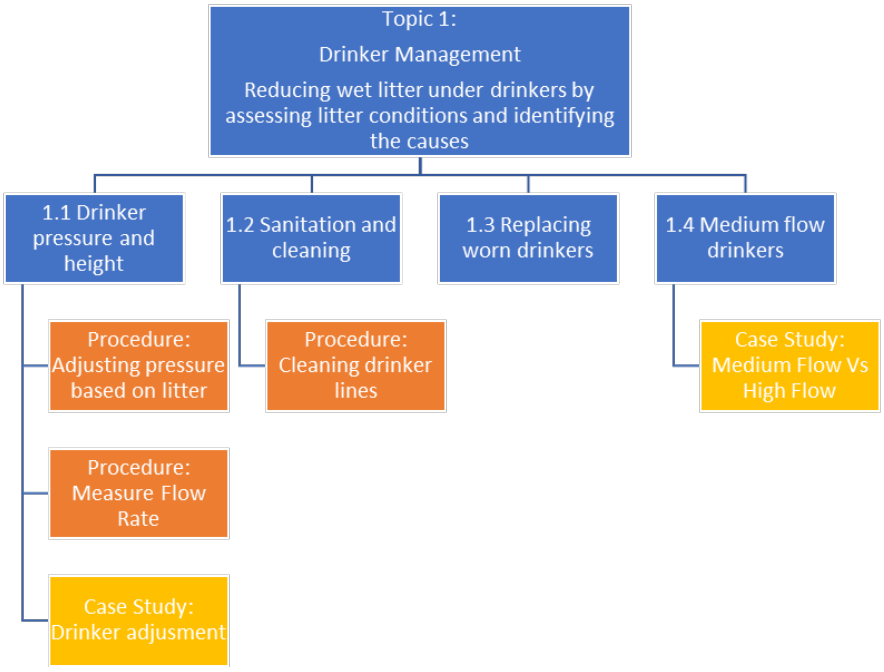


Figure 18. Topic 1 – drinker management fact sheets and resources.

Keeping litter dry and 'working'

This topic consists of fact sheets and case studies about litter tilling and the management required to keep different bedding materials friable and 'working', which is the process by which chicken activity incorporates fresh excreta into the litter (Figure 19). The associations between litter tilling and ammonia concentration were also included in the fact sheet, with this information derived from measurements of ammonia during this project. Litter tilling is a practice developed by growers and as such there is minimal published information about it. The case studies shared the experiences of several growers to inform others about techniques that contribute to maintaining friable litter. It is hoped additional growers will share their litter tilling experiences in the future and that these will be added to *Litterpedia*.

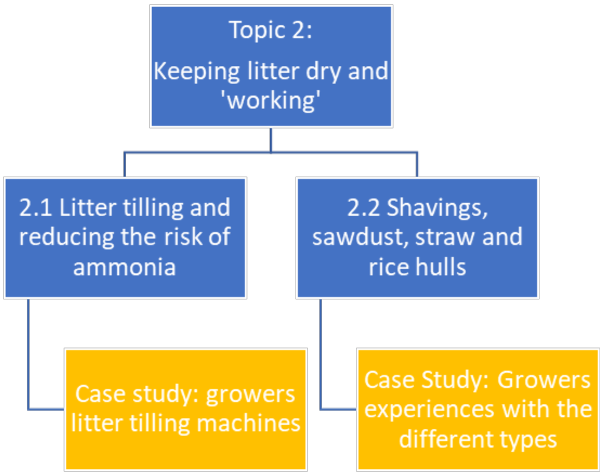


Figure 19. Topic 2 – keeping litter dry and 'working' fact sheets and resources.

Ventilation

Ventilation fact sheets focused on the essential elements of drying litter (heat, air movement, water availability) as well as preparing the shed and litter to improve the potential for reliably achieving longer-term dry and friable litter (Figure 20). Pre-heating and drying the litter before placement of day-old chicks was considered a high priority by the industry committee. Drying the litter before the grow-out starts is essential for the success of litter management during the batch. Having dry litter increases water holding capacity and allows the litter and shed floor to achieve the temperatures required to keep chicks warm.

Coinciding with this project was research into higher-power circulation fan systems (Mou, 2020, 2021). Circulation or stirrer fans are not uncommon in Australian meat chicken sheds (according to the industry survey), but the most recent concepts focus on creating more airspeed to increase evaporation and litter drying. This is above and beyond the traditional concept of improving the distribution of heat and humidity throughout the shed. A fact sheet on stirring fan systems was produced, and included case studies on different systems and how circulation fans enhance litter drying.

The effects of ventilation on litter drying are very complex due to interactions between temperature, relative humidity, litter moisture content and availability of water, which might change with litter tilling or other disturbances. Computer-based models were developed in this project to investigate the effect of different environmental conditions (i.e., temperature and relative humidity) and management practices (i.e., heating practices, tilling intervals and in-shed air speed). These models simulate evaporation under controlled conditions and enable testing of modified practices, neither of which are possible at commercial farms. It also is not possible to reproduce the complexity that occurs in commercial farms in laboratory-based experiments. Outputs from the models were used to support the information provided in the fact sheets on litter drying.

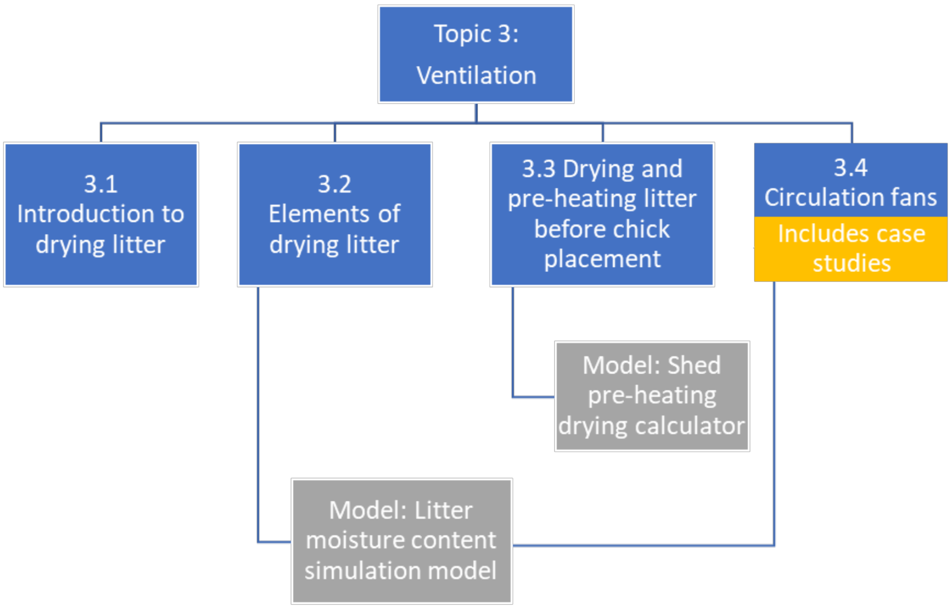


Figure 20. Topic 3 – ventilation fact sheets and resources.

Litter condition assessment

A fact sheet was created to complement the *Litter Guide – Daily litter condition assessment* (Figure 21), which was previously developed in consultation with an industry committee. The *Litter Guide* provides consistent litter assessment methods, terminology and suggestions for a variety of corrective actions.

The fact sheet provided more details for the litter assessment process and definitions of the moisture and friability terms used in the scoring table. It also provided additional guidance on when to take corrective action and the types of litter management actions that are likely to improve litter conditions. The fact sheet also provided links to other resources (such as videos and animations) that relate to assessment and managing litter.

Figure 21. Example of pages in the *Litter Guide – Daily litter condition assessment* (AgriFutures Chicken Meat Program).

Implications and recommendations

Litterpedia provides a single location for resources and information about litter management. The troubleshooting guide will help readers find information relating to the issues or problems they are searching for. The topic-by-topic webpage format enables individual topics to be updated as required to keep the information current and relevant.

We recommend that AgriFutures Australia provides ongoing support to host *Litterpedia*, and that the information, fact sheets and other resources be reviewed regularly and updated as necessary in consultation with an industry committee to ensure information continues to be readily available and relevant for growers.

Assessing litter with the Litter Guide

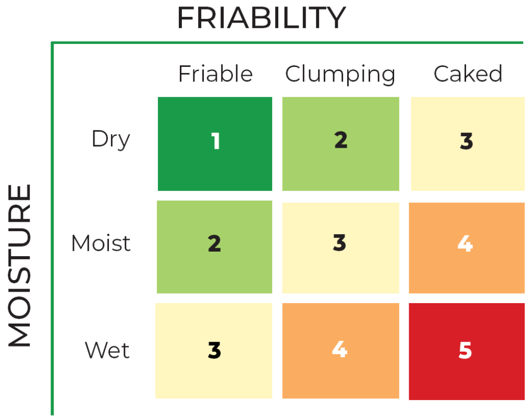
Background

Assessing litter conditions in a meaningful way can be quite challenging. In general, the intention is to quantify potential risks associated with the litter by qualitatively describing its appearance and/or physical characteristics and, more specifically, moisture content and friability. If the litter is too dry, it might increase the amount of dust in the shed, and this has been associated with increased risk of respiratory issues. If the litter is too damp, it reduces thermal insulation and increases the risk of footpad, hock or skin lesions, microbiological challenges and higher ammonia concentrations. If litter has lost friability, is too shallow or has a crusted/caked surface, then the cushioning properties of litter is reduced and may contribute to reduced comfort or increased risk of pressure-related contact injuries.

Multiple litter assessment protocols have been developed to assess litter. Some scoring systems focus predominately on litter moisture (GAP, 2017; Tucker and Walker, 1992; Welfare Quality®, 2009), while others rate both the moisture and caking (van Harn *et al.*, 2017; Veldkamp *et al.*, 2017; Weaver and Meijerhof, 1991).

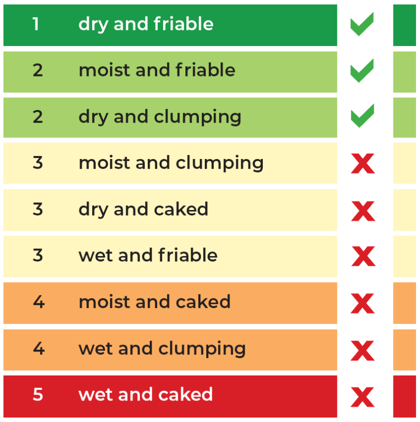
From a litter function perspective, both the moisture and friability are relevant measures of quality, although the previously developed litter assessment methods do not readily allow for some conditions to be recorded. To address these challenges and to have a more flexible, easy-to-use litter scoring method, the *Litter Guide – Daily litter condition assessment* (Figure 21) was previously developed in consultation with an Australian chicken meat industry committee.

The *Litter Guide* provides consistent litter assessment methods, terminology and suggestions for corrective actions. The process requires assessment of litter in multiple locations in the shed, including two locations under drinker lines. Moisture and friability conditions are assessed individually and then an overall score (1-5) is determined using a scoring matrix (Figure 22). The litter score determines if corrective actions are required to minimise welfare risks, but also to be proactive in preventing litter conditions declining to a point where they may increase the risk of health or welfare issues (Figure 23). A score of 1 or 2 indicates good litter conditions. A score of 3 or above requires corrective action, with the urgency and scale of the intervention increasing if the litter is scored with a 4 or 5.



MOISTURE	FRIABILITY		
	Friable	Clumping	Caked
Dry	1	2	3
Moist	2	3	4
Wet	3	4	5

Figure 22. Litter assessment scoring matrix.



1	dry and friable	✓
2	moist and friable	✓
2	dry and clumping	✓
3	moist and clumping	✗
3	dry and caked	✗
3	wet and friable	✗
4	moist and caked	✗
4	wet and clumping	✗
5	wet and caked	✗

Figure 23. Litter scores (1-5) and descriptors.
The ✓ or X indicates whether the score is acceptable or if corrective action is required.

In this investigation, we compared moisture content (%) to scores for moisture, friability and overall quality. This exercise was not intended to be a formal assessment of the *Litter Guide – Daily litter condition assessment* methodology, but it was an opportunity to investigate how well the litter scores differentiate different litter conditions based on their moisture content.

Methods

The following chapters in this report describe two activities where ammonia and odour were measured during litter disturbance events. In each of the sampling events, litter was sampled for moisture content analysis, and litter conditions were scored. Litter was collected across four sampling transects (two in the front half of the shed and two in the rear). Multiple small samples were collected from the surface 1–2 cm of the litter along each transect.

Surface litter was collected because chickens directly interact with it. These samples were then combined to create a representative sample of the respective area within the shed. For each transect, additional samples were collected of visibly dry, and visibly damp litter. The damp litter was usually collected under the drinker lines. In some cases, no litter was visibly wetter and so a sample was taken from under the drinker lines by default. For each litter sample, moisture content was determined by the loss of water mass after drying the samples in an oven at 105 °C.

Litter was assessed before and after litter disturbance by tilling or chicken pick-up events. The data presented below is only from the 'before' disturbance events, due to both the moisture and friability of the litter surface being changed as a result of litter tilling or machinery operating in the shed.

The litter assessment process was performed by two people, with a single score being agreed by consensus for each of the four transects in the shed. Litter moisture, friability and overall score were compared to the measured moisture content (all data including the transect average as well as dry and wet grab-samples were combined into a single data set). Data was presented using boxplots.

Results and discussion

There were relatively distinct differences in litter moisture content between the different moisture score categories, with a transition from dry to moist occurring at 30–32% moisture content, and a transition of moist to wet occurring at approximately 38–40% moisture content (Figure 24).

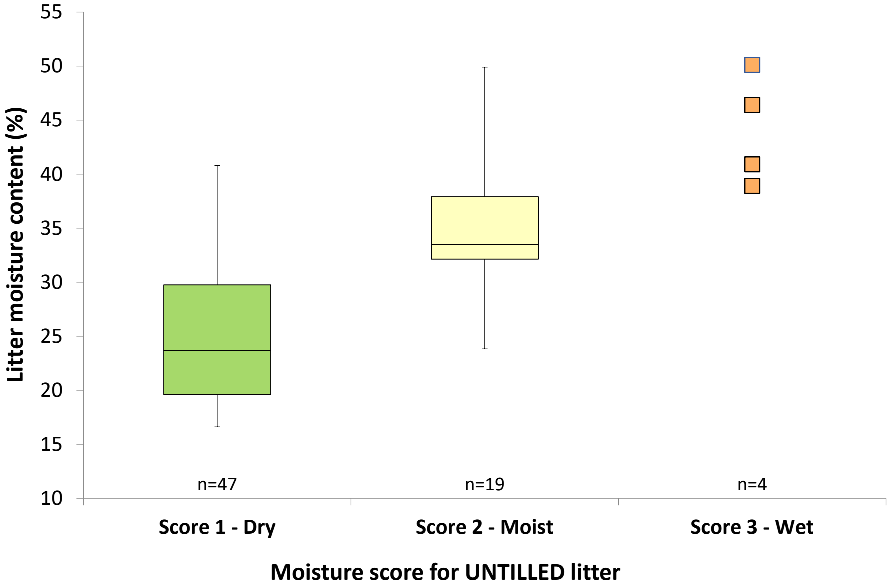


Figure 24. Boxplot showing moisture content (%) for litter moisture scores.

Boxes represents the 25th to 75th percentile; the line in the middle of the box is the median value (50th percentile); and the whiskers represent the maximum and minimum values. Individual data points were shown if there was insufficient data to produce a box with whiskers.

Similar differences were apparent in litter moisture content between the friability score categories, with a transition from friable to clumping occurring at about 29–32% moisture content, and a transition of moist to wet occurring between 34% and 38% moisture content (Figure 25).

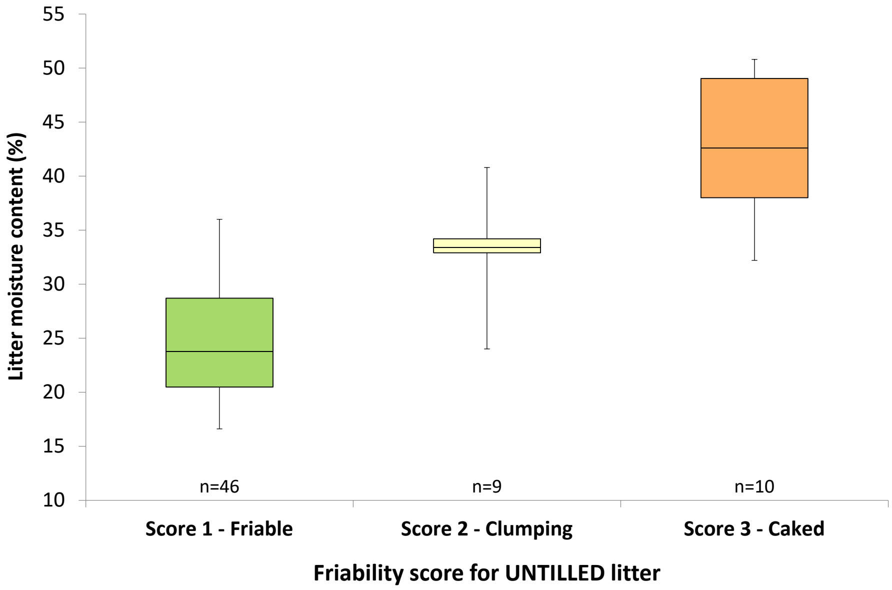


Figure 25. Boxplot showing moisture content (%) for litter friability scores.

Boxes represent the 25th to 75th percentile; the line in the middle of the box is the median value (50th percentile); and the whiskers represent the maximum and minimum values.

The combined moisture and friability scores showed a trend for moisture content to increase as litter scores transitioned from 'dry and friable' (score 1) to 'wet and caked' (score 5) (Figure 26). There was also a clear transition between score 1 and score 2 at 26–29% moisture content. This aligns reasonably well with previous recommendations to keep litter moisture content below 25% to maintain its beneficial properties of being insulating, cushioning and able to hold water (Collett, 2012). The upper threshold of score 2 litter (described as either 'dry and clumping' or 'moist and friable') was approximately 36% moisture content. According to the explanations in the *Litter Guide*, these litter conditions are satisfactory and do not need corrective actions, which aligns with previous reports that 'good litter' has a maximum moisture content of 25% to 35% (Lister, 2009).

There were only a limited number of data points for score 3, 4 and 5 litter conditions but litter scores tended to increase with litter moisture content (%). Based on our observations, the low occurrence of these litter conditions was due to growers actively managing litter to keep it dry and friable. Score 3 had a wide range of moisture content from approximately 24% to 43%, which was not surprising given that it included litter conditions from 'dry and caked' through to 'wet and friable'.

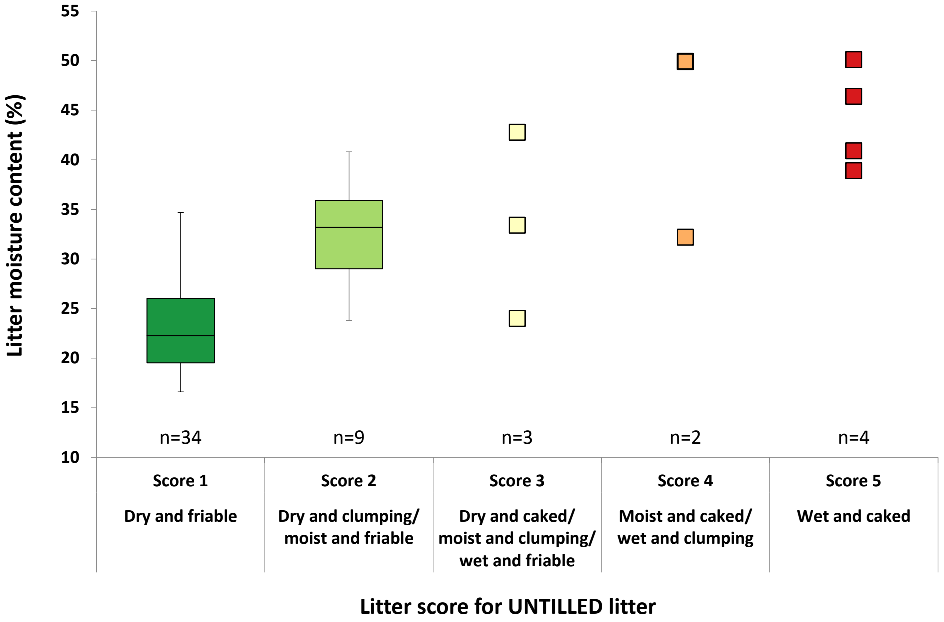


Figure 26. Boxplot showing moisture content (%) for litter quality scores.

Boxes represent the 25th to 75th percentile; the line in the middle of the box is the median value (50th percentile) and the whiskers represent the maximum and minimum values. Individual data points were shown if there was insufficient data to produce a box with whiskers.

Implications and recommendations about litter assessment

This activity showed a close relationship between the litter scores described in the *Litter Guide – Daily litter condition assessment* and moisture content. This assessment method enables litter conditions and moisture to be quickly assessed on commercial farms or in research situations.

While this comparison exercise focused on the relationship between litter moisture content (%) and scores for litter moisture, friability and overall condition, it would be beneficial to relate litter scores to measurable health, welfare and production-related outcomes. This should be considered for future research.

Ammonia and carbon dioxide

Background

Litter tilling, also known as conditioning, stirring or turning, involves using machinery to improve litter friability by reducing clumps and caking with a cutting or pulverizing action (Pepper and Dunlop, 2021). When litter is friable, the chickens are more readily able to "work" the litter (Lister, 2009), which is the process by which chicken activity incorporates fresh excreta into the litter.

Litter tilling may help reduce the occurrence of wet litter. It involves mixing wet litter with dry litter, resulting in a combination that is less dusty and less likely to cake. Additionally, when combined with effective ventilation, litter tilling can accelerate the drying process. The industry survey revealed that growers held concerns about possible impacts of litter tilling on chicken wellbeing, especially due to increased ammonia concentrations. Growers also reported that litter tilling was beneficial when used appropriately in combination with effective ventilation, husbandry and drinker management practices.

Previous research revealed concerns about and advantages of litter tilling in chicken sheds. For example, litter tilling has previously been associated with concerns about animal stress, exposure to aerosols and pathogens, and increased ammonia concentrations that may affect bird health (Brink *et al.*, 2022; Dezat and Gohier-Austerlitz, 2000; Ivulic *et al.*, 2022; Malone and Marsh Johnson, 2017; Taira *et al.*, 2014).

In support of litter tilling, some research has shown it tends to immediately decrease litter moisture at the surface, with which birds are in contact (Taira *et al.*, 2014). This is achieved by mixing the wetter surface layer with the drier litter underneath and around the sides. Tilling has also been shown to increase surface area and release water, which assists with managing moisture content in the longer term (Koon *et al.*, 1994). On the other hand, some research has found that tilling makes no significant difference to litter moisture (Brink *et al.*, 2022; Nuñez Casas, 2011).

The mechanisms involved in ammonia emission from the litter are complex, but increases with pH, moisture and temperature (Elliott and Collins, 1982). Previous research has shown conflicting results. Constantly aerating litter or regularly stirring has been shown by some researchers to reduce ammonia and moisture content (Allen *et al.*, 1998; Boggia *et al.*, 2019; Koon *et al.*, 1994).

On the other hand, some research has shown that regularly stirring litter increased ammonia emissions due to the increased friability and pH (Brink *et al.*, 2022). This aligns with other research that found that wet and caked litter has low pH and low ammonia emissions (Miles *et al.*, 2008). Disturbing litter with tilling has been reported to cause an immediate 'spike' of ammonia due to the release of trapped ammonia from beneath caked or compacted litter (Bilgili *et al.*, 2009; Chai *et al.*, 2018; Malone and Marsh Johnson, 2017; Nuñez Casas, 2011; Ritz *et al.*, 2006; Tabler and Wells, 2018). This may increase certain risks to the health and wellbeing of the birds and farm workers.

The concentration of ammonia in the shed is affected by multiple factors (Cockerill *et al.*, 2020; Miles *et al.*, 2006; van Emous *et al.*, 2019) including:

- Ammonia production in the litter (affected by diets, pH, temperature, manure and moisture)
- Ammonia exchanged between the litter and the air
- Dilution and removal of ammonia due to the rate of air exchange by the ventilation system.

With so many conflicting experiences and viewpoints about the effect of litter tilling on ammonia emissions, further research was required to quantify variations in ammonia concentration during and after litter tilling under Australia production conditions.

Objectives

The primary objective was to quantify in-shed ammonia (NH_3) and carbon dioxide (CO_2) concentrations during and immediately after litter tilling, when the expected ‘spike’ in these gas emission from the litter may create a potential risk to the chickens.

Another objective was to measure ammonia flux from the litter surface using an isolation flux chamber. This was conducted to get a greater understanding of how litter conditions affect ammonia production, primarily focusing on the effect of moisture content. Measuring ammonia emissions directly from the litter with an isolation flux chamber does not indicate the exposure of chickens to ammonia, but was undertaken for two specific reasons:

1. The industry survey revealed that growers routinely increased the ventilation rate during litter tilling, which would mask the relative increase in ammonia compared to before tilling. Measuring ammonia flux directly from litter was believed to be the best way to measure the increase in ammonia emissions relative to the undisturbed pre-tilling conditions.

2. Litter moisture content and surface caking were expected to affect ammonia released during tilling. Measuring only the in-shed concentration would not show the effect litter condition has on ammonia emissions. Isolating specific spots and sequentially measuring ammonia emissions before, during and after tilling would provide a much greater understanding of the effect different litter conditions have on ammonia emissions and whether tilling practices may need to be altered accordingly.

Methods

Selection and description of farms

In-shed ammonia concentrations were measured at farms in South East Queensland (Table 7). Each of the farms had mechanically ventilated sheds, performed regular tilling as part of their normal litter management practices and used either new bedding or re-used litter each grow-out. Farms were also chosen based on their ability to record and download ventilation data (but unfortunately, as the activities progressed, technical issues at two of the farms prevented the data from being recorded by the ventilation computer).

Farms tilled their litter approximately weekly after brooding had finished. Tilling was not performed after day 28, due to potential risks associated with tilling just before the thin-out, which usually occurs on day 31-34. At Farms A1 and A2, litter was tilled using a tractor-driven power harrow while the remaining farms used a purpose-built, tractor-driven litter tilling implement.

At each of the farms, the grower increased ventilation by turning on more fans or increasing the speed of the variable speed fans to increase the ventilation rate. There was no consistency in how ventilation was increased on each sampling day. It was also challenging to determine how much the ventilation was increased above normal levels because ‘normal’ ventilation automatically responded to diurnal temperature changes. In most cases, the grower returned the ventilation system to automatic within one to two hours after tilling.

Table 7. Details of the farms used during ammonia and carbon dioxide measurements.

Farm	Sampling period	Chicken age – for in-shed gas concentrations	Chicken age – ammonia flux measurements	Litter	Shed dimensions	Ventilation
A1 (Farm A, Shed 1)	Jul-Aug 2021	14-15; 21-22; 28-29	14; 21; 28	Fresh	164 m x 17.3 m	All farms had variable speed fans with maximum ventilation rate approximately 500,000-550,000 m^3/h
A2	Sept-Oct 2021	1-22	14; 21	Re-used	164 m x 17.3 m	
B	Apr-May 2022	18-20; 27-29; 32-34	(No litter NH_3 flux measurements)	Re-used	150 m x 17 m	
C	Apr-May 2022	4-35	12; 19; 26 (on day 26 tiller broke down and litter was stirred by hand on the sampling spots)	Fresh	161 m x 18 m	
D1**	May 2023	24-28	26	Re-used	164 m x 17.3 m	
D2**	May 2023	33-37	36	Re-used	164 m x 17.3 m	

**Note: Ammonia measurements had not been planned for D1 and D2, but were undertaken as a result of the tilling machine breaking down after day 19 at Farm C. Farm D was chosen because the chickens were the desired age (26 and 36 days), but measurements needed to be made in separate sheds due to the pick-up schedule.

Litter tilling methods

At Farms A1 and A2, litter was tilled using a tractor-driven power harrow while the remaining farms used a purpose-built, tractor-driven litter tilling implement. Each grower followed a different pattern in the shed while tilling. Selecting the tilling patterns depended on grower preference, machinery size/width, chicken age and chicken density. The patterns included:

- Starting along one sidewall and then going back and forth along the length of the shed as they worked from one side of the shed to the other. Sometimes, one-quarter to half of the shed width was tilled before encouraging the chickens to move onto the tilled area. At other times, chickens were encouraged onto the tilled area after each pass of the tractor.
- Starting along one sidewall and following a circular ‘racetrack’ style path through the whole shed, working towards the middle.
- Starting along one sidewall and following a circular ‘racetrack’ style path in one half of the shed. Once completed, chickens were encouraged onto the tilled litter to enable the other side of the shed to be tilled.

Litter sampling, moisture content analysis and scoring

Litter samples were collected across four sampling transects for each litter tilling event. Two were in the front half of the shed and two were in the rear, where cool-pads and tunnel ventilation fans were installed, respectively. Across each transect, multiple small samples were collected from the surface 2 cm of the litter where it has the most contact with the chickens. The samples were combined to form a representative sample of that area in the shed. Additional grab samples were also collected at each transect of visibly dry and visibly wet litter. Wet litter samples were usually collected under the drinker lines, but if there was no visibly wet litter, a sample was taken from under the drinker lines by default. For each litter sample, moisture content was determined by the loss of water mass after drying the samples in an oven at 105 °C.

Litter was scored using the *Litter Guide – Daily litter condition assessment* method. The litter assessment process was performed by two people, with a single score being agreed by consensus for each of the four transects in the shed. Litter moisture, friability and overall scores were compared to the measured moisture content (all data including the transect average as well as dry and wet grab-samples were combined into a single data set).

Litter moisture content at the location of each ammonia emission measurement was determined by collecting litter samples from the same location where flux chambers were installed.

In-shed ammonia and carbon dioxide concentration measurement

Ammonia and carbon dioxide were measured by temporarily installing sensors into each shed on portable tripod stands. These sensor stations also had a data logger (HOBO UX120-006M; Onset Computer Corporation, Bourne, MA, USA), temperature and relative humidity sensors and a battery (refer to Table 8 for sensor specifications). Two of these sensor stations were used in each shed and were positioned as close as possible to the chickens' head height to observe their experience. A third sensor station with only ammonia, temperature and relative humidity sensors was placed inside the sheds at the exhaust fan to measure what was being ventilated out of the shed.

Sensors were placed at their respective positions with an adjustable stand arm used to alter the height of the sensors to approximately chicken head-height (Figure 27). The data logger was configured to collect data every 15 seconds. At the end of each sampling day, data was downloaded for processing and analysis. When processed, 15-minute averages were calculated for time periods from 24 hours before tilling to 24 hours after tilling:

- Before tilling: 24, 21, 18, 12 hours
- Immediately before tilling: 0.3 hours (20 min)
- Immediately after tilling: Maximum continuous 15-minute average within three hours of tilling
- After tilling: three, six, 12, 24 hours.

Table 8. Specifications for sensors used to measure in-shed gas concentrations.

	Specifications		
Sensor	**Model**	**Measurement range**	**Accuracy**
Relative humidity	DOL 114 (dol-sensors A/S, Denmark)	0–100%	± 2% RH (40–85%) ± 3% RH (10–95%)
Temperature	DOL 114 (dol-sensors A/S, Denmark)	-40–60 °C	± 0.5 °C (at 10–40 °C) Otherwise ± 1.5 °C
Carbon dioxide	DOL 19 (dol-sensors A/S, Denmark)	0–10,000 ppm	0-7,000: 50 ppm +5% of measuring value
Ammonia	DOL 53 (dol-sensors A/S, Denmark)	0–100 ppm NH3	1.5 ppm or ± 10% of measured value

Figure 27. In-shed sensor stations (left – main in-shed sensor; right – the fan-stand).

Measurement of ammonia emissions from the litter using isolation flux chambers

> **The concentration measured within a flux chamber HAS NO RELATION to that experienced outside of the chamber by the chickens due to the very low sweep-air flow rate within the chamber.**

Flux chambers (Figure 28 and Figure 29) were used to measure the emission rate of ammonia directly from the litter surface. These chambers are a scientific device that were designed to enable measurement of gas emission rates from area sources which, in this case, was poultry litter. Flux chambers, like any area source enclosure device, can affect the true emission rate but they are suitable for comparison studies (Smith and Watts, 1994; Zhang *et al.*, 2002). The purpose of using the flux chambers in this study was to complement the in-shed gas concentration measurements and grow an understanding of the effects litter conditions have on ammonia production, and to isolate the measurement from other controlling factors in the shed, such as ventilation rate and chicken activity.

Ammonia measurements were performed before, during and after litter tilling, and once more on the following day. The 'after' measurement was performed approximately 1.53 hours after tilling finished. In each end of the sheds, a wet (usually under a drinker line) and dry patch of litter were selected for ammonia measurements (four locations per shed). Two flux chambers were used, enabling the wet and dry measurement locations in each end of the shed to be measured simultaneously before moving to the other end of the shed and repeating the process.

Flux chambers were designed and operated according to AS/NZS 4323.4-2009 (Standards Australia/ Standards New Zealand, 2009) with the exception of an ammonia sensor (DOL 53, dol-sensors A/S, Denmark, Table 8), which was installed inside the chamber and connected to a data logger (HOBO UX120-006M; Onset Computer Corporation, Bourne, MA, USA). This enabled direct and continuous measurement of the concentration of ammonia within the chamber. The logger was programmed to record ammonia concentration every five seconds, and it updated the displayed concentration every 30 seconds. Ammonia sensors were calibrated before use with 50 ppm ammonia calibration gas.

Compressed 'instrument grade' air was used as sweep air in the chamber. The sweep air flushing rate was set to 5.0 L/min using a calibrated TSI Series 4143 flow meter (TSI Inc., Shoreview MN, USA). Flow rate was controlled by setting the sweep gas line pressure with a dual-stage regulator for highpurity gases, and then finely adjusting the flow rate with a Uniflux 0-13 L/min rotameter (model SSVI1S9AI08, Influx Measurements Ltd, Hampshire). Flow rate was visually monitored during measurement using the rotameter.

Figure 28. Flux chamber along with sweep-air cylinder, flow regulator and data logger used to measure ammonia emissions from litter.

Figure 29. Close-up view of the ammonia sensor mounted inside the flux chamber.

Ammonia measurements were performed by placing the chamber on a patch of litter and monitoring the ammonia concentration until a steady-state concentration was achieved. According to the standard, a 24-minute equilibrium time was required before collecting a sample. With the benefit of having the ammonia sensor installed in the chamber, adhering to this equilibrium time was not required because the operator could observe the concentration within the chamber and make an informed decision for when the chamber had achieved steady state conditions. The operator recorded the displayed concentration on a record sheet (Figure 30) so that they could determine when the concentration stabilised at a peak value, at which point the measurement could be ended.

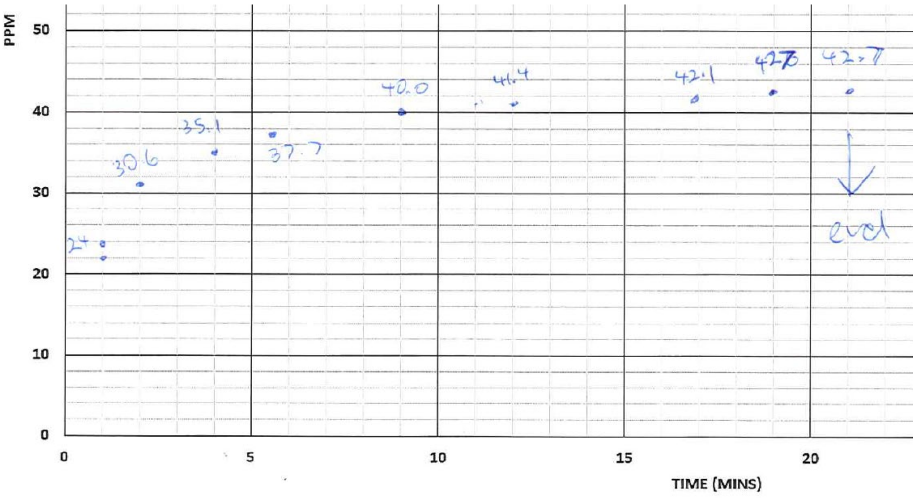


Figure 30. Example of the flux chamber record sheet where the operator could record the displayed ammonia concentrations (ppm) throughout the measurement period.

Some concentrations in the flux chamber exceeded the maximum range of the sensor (100 ppm). On these occasions, colorimetric ammonia detection tubes and a sampling pump (Gastec Corporation, Japan, https://www.gastec.co.jp/en/) including Gastec 3La (2.5-220 ppm NH_3), Gastec 3M (2-1000 ppm NH_3) along with a Gastec sampling pump (model GV-100) were inserted in the hood and used to measure the ammonia concentration in the flux chamber once it reached equilibrium conditions after 24 minutes.

Statistical analysis

General linear models (GLMs) were used to analyse the data, using Genstat (2022). The normal distribution with the identity link function was adopted, and residual plots were used to check the assumptions of homogeneous variances and low skewness. The fixed effects were:

- Age of the chickens (day of the grow-out)
- Litter location (dry or wet flux chamber locations)
- Bedding material (pine-based, hardwood-based or re-used litter)
- Sample timing (before tilling, immediately after tilling, hours after tilling or next day).

Interactions were screened but generally found to be non-significant and were omitted; however, some interactions such as ‘location by sample timing’ and ‘bedding material by age’ were retained as they were of primary interest.

Results and discussion

Observations of litter tilling

Each of the litter tilling machines produced friable litter with very few clumps larger than 10–40 mm in size. Litter appeared to be more homogeneous after tilling, although sideways mixing of litter was not thorough, and there was often a visible strip of moist litter left underneath the drinkers. Based on these observations, there is an opportunity for improving the design of the tilling implements to completely mix and evenly re-distribute litter across the entire width of the machine. We suggest that achieving complete mixing of wet and dry litter would help to reduce the litter moisture under the drinkers and make it less prone to re-caking. Ideally, this will reduce the number of tilling events needed during each grow-out.

It was interesting to observe chicken behaviour during tilling. Chickens normally moved calmly and easily around the machinery but there were times when they were less inclined to move when required. Chickens needed to move onto tilled areas to make room for the machinery to access the untilled areas and they sometimes seemed hesitant to move onto freshly tilled litter despite freely engaging with it once they were on it by dustbathing, scratching and pecking.

These observations point to a potential opportunity for behavioural research to investigate ways to take advantage of the chickens’ natural and instinctive behaviours to help them move more readily around tilling equipment. If successful, it may reduce the risk of injuries, fear and stress, as well as make tilling easier for growers and farm workers.

Litter moisture content and condition scores

Litter moisture content and condition scores associated with in-shed ammonia concentrations

Litter condition scores and moisture content data from the in-shed ammonia experiments were analysed statistically after being combined with data that was collected during the later odour experiments. This was to increase the number of data points and improve interpretation of the effects tilling has on litter conditions. Results from the statistical analysis are described in the following chapter along with the odour data. The data included in this chapter are to improve general understanding of the effect of litter conditions on ammonia and carbon dioxide.

Litter scores showed that the litter before tilling was mostly dry or moist, and its friability was most frequently scored as friable or clumping (Figure 31). Caked litter was only found under the drinker lines. Following tilling, all caked litter was broken up and returned to friable or clumping litter; however, some cake had re-formed by the following day.

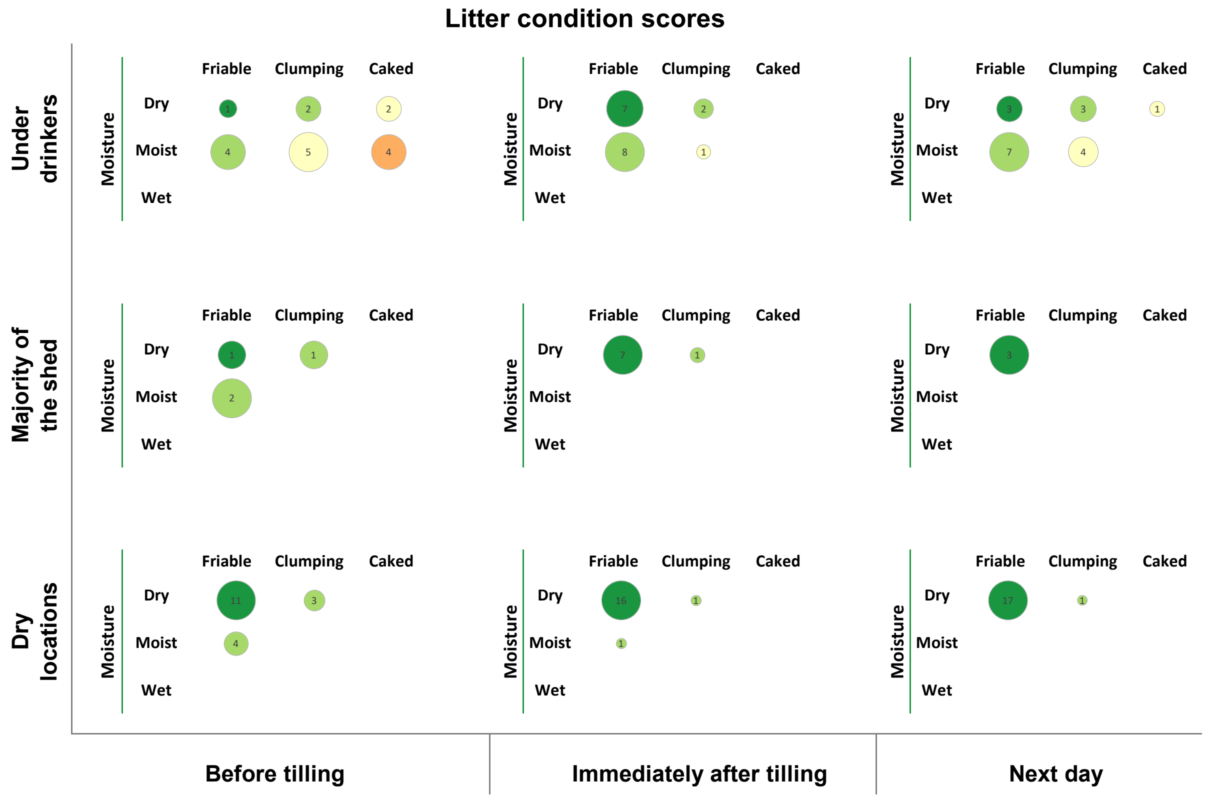


Figure 31. Bubble charts showing the frequency distribution of litter moisture, friability and overall condition scores at time points before and after tilling, and on the day after tilling. Bigger bubbles represent higher frequency. Refer to Figure 22 for the scoring matrix.

Litter moisture content changed following tilling throughout the majority of the shed and underneath the drinkers (Figure 32). In dry locations, however, tilling barely changed the litter moisture content, but the moisture content was much drier than the rest of the litter throughout the shed. The reduction in moisture content in the majority of the shed was approximately five percentage points and this was sustained until the following day. The litter underneath the drinkers dried by approximately eight percentage points immediately after tilling, and by the following day was still four percentage points drier than it was before tilling.

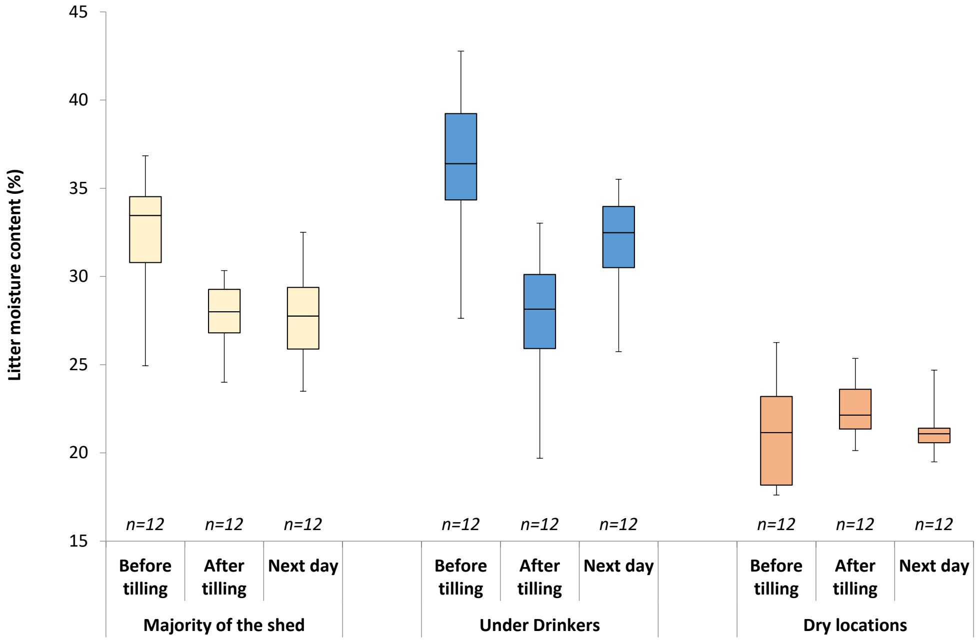


Figure 32. Boxplot of litter moisture content throughout the sheds at time points before and after tilling, and on the day after tilling.

Boxes represent the 25th to 75th percentile; the line in the middle of the box is the median value (50th percentile); and the whiskers represent the maximum and minimum values.

Litter moisture content and scores for flux-chamber locations

For the flux chamber locations, a significant two-way interaction ($P < 0.05$) between location (wet or dry) and sample timing (before or after tilling, or next day) affected litter moisture content. Tilling had an effect of immediately reducing the moisture content in the wet locations by five percentage points, but there was negligeable change in the dry locations (Figure 33).

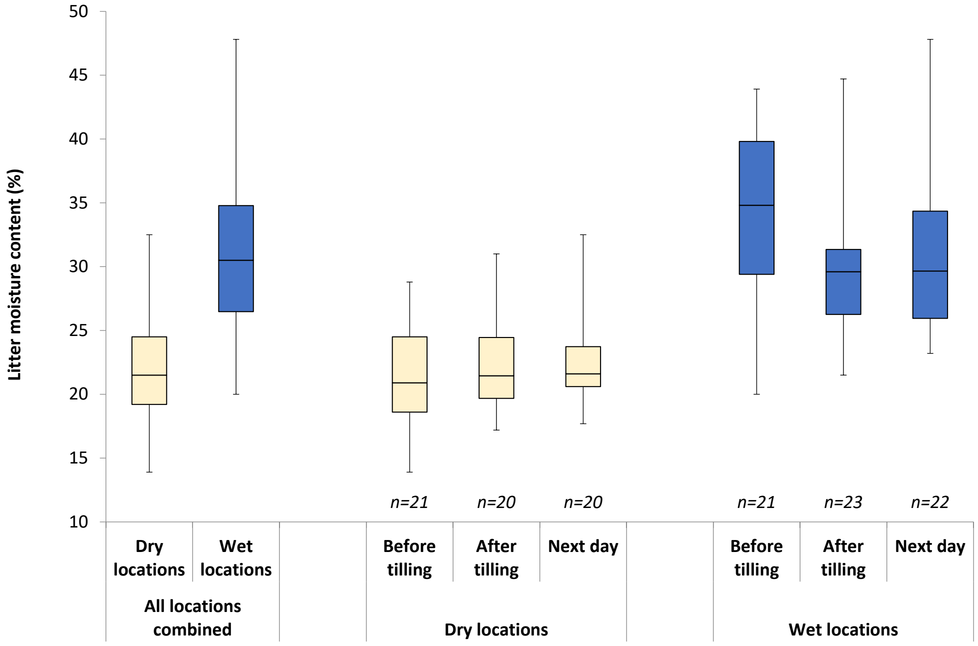


Figure 33. Boxplot of litter moisture content at different locations in the sheds at time points before and after tilling, and on the day after tilling.

Boxes represent the 25th to 75th percentile; the line in the middle of the box is the median value (50th percentile); and the whiskers represent the maximum and minimum values.

Litter moisture content was also affected by another two-way interaction between the days of the grow-out and different bedding materials ($P < 0.01$). On days 12–15, the moisture content of pine and re-used litter were similar, although the re-used litter was numerically slightly wetter (Figure 34). It is suggested that this was most likely due to residual moisture from the previous grow-out because brooding had only just finished, and chickens had not been allowed access to the re-used litter (due to partial litter re-use practices).

By days 19–22, re-used litter tended to be drier than pine-based litter. Re-used continued to become drier, relative to the pine-based litter, as the grow-out continued. By day 36, when litter moisture measurements ended, the re-used litter was more than six percentage points drier than the pine-based litter. Reasons for the difference may include differences in live-weight density or ventilation in the opposing ends of the shed (with pine-based litter in one end and re-used litter in the other), but it is suggested that there may be other reasons for the re-used litter having lower moisture content. These include:

- Re-used litter has higher water absorbing capacity than pine-based litter (Dunlop, 2014; Dunlop *et al.*, 2015), which means that the same volume of re-used litter can hold more water at the same moisture content (%).
- Re-used litter was deeper in the shed, which means there was a greater volume of re-used litter and therefore it could absorb more water.
- Re-used litter has greater biological activity, which produces heat that increases the evaporation of water from the litter.

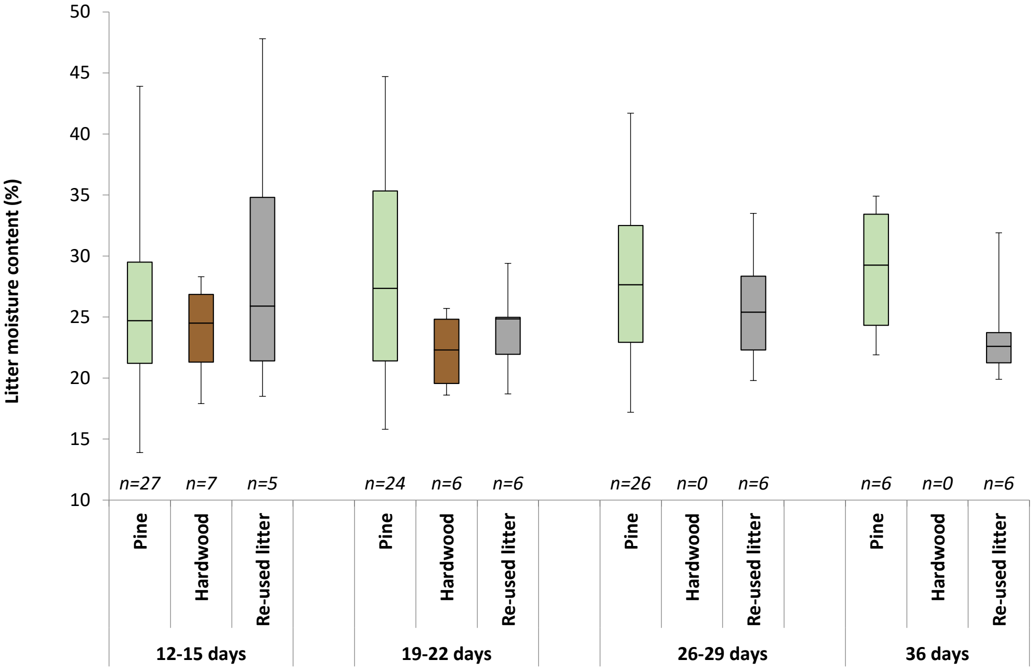


Figure 34. Boxplot of litter moisture content for different bedding-based litter materials on ammonia measurement days during the grow-out.

Boxes represent the 25th to 75th percentile; the line in the middle of the box is the median value (50th percentile); and the whiskers represent the maximum and minimum values.

Moisture scores were dominated by two-way interactions ($P < 0.05$) between the different types of bedding material (pine, hardwood or re-used litter) and litter location (wet or dry). For wet litter locations under the drinkers, re-used litter was more frequently scored as ‘dry’ whereas the pine/hardwood bedding materials tended to be scored as ‘moist’ (Figure 35).

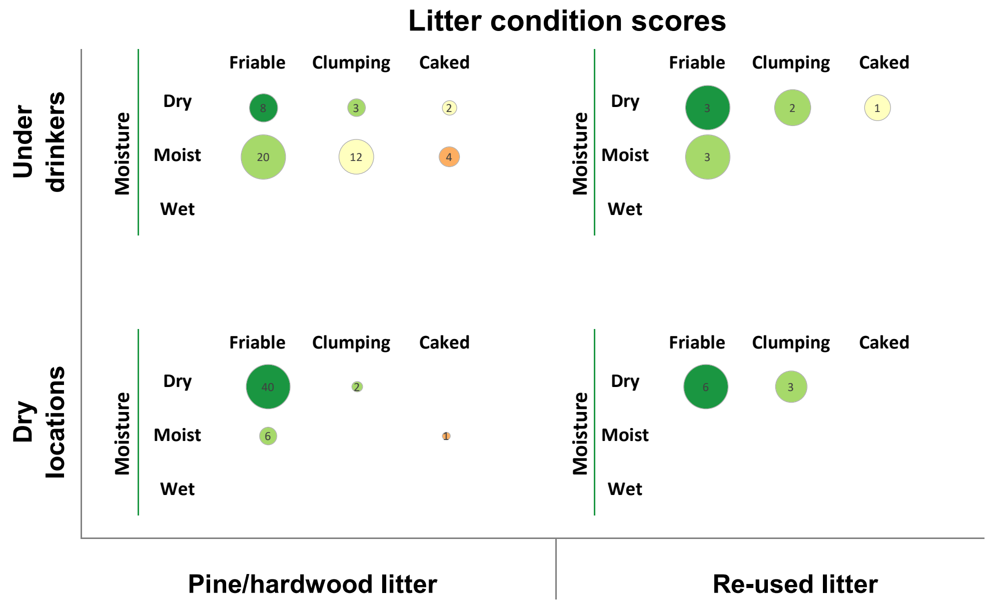


Figure 35. Bubble charts showing the frequency distribution of litter moisture, friability and overall condition scores for the flux chamber sampling points for new bedding-base litter or re-used litter. Bigger bubbles represent higher frequency. Refer to Figure 22 for the scoring matrix

Litter friability scores were dominated by a two-way interaction ($P < 0.01$) between sampling location (wet or dry) and sample timing (before or after tilling, or next day). The litter score data showed that the wet litter locations under the drinkers had a higher incidence of clumping and caking than the dry locations (Figure 36). Tilling eliminated caked litter and returned most litter conditions to friable or clumping. In the dry litter locations, changes in friability were negligible, but most of the litter was already friable before tilling.

Litter condition scores were dominated by two significant, two-way interactions:

- Sampling location (wet or dry) by bedding material ($P < 0.01$).
- Sampling location (wet or dry) by sample timing (before or after tilling, or next day) ($P < 0.01$).

Given the moisture score was significantly affected by bedding material and the friability score was affected by sample timing, we suggest that bedding material had a greater influence on the moisture component, possibly relating to water holding/evaporation properties, while tilling had a greater influence on friability.

Tilling was proven to be effective with condition scores for the wet litter being reduced from an average before-tilling score of 2.8 to 1.7 immediately after tilling, and 2.1 on the next day. Dry litter scores were also improved by tilling, with reductions from an average of 1.4 before tilling to 1.1 after tilling and on the next day. To further reinforce the value of tilling as a corrective action, litter that scored 4 before tilling had scores of 1 or 2 after tilling. This meant that litter conditions changed from ‘moist and cake’ or ‘wet and clumping’ before tilling, to ‘dry and friable’, ‘moist and friable’ or ‘dry and clumping’) afterwards. On a few occasions, there was a slight decline in litter quality on the following day, with some litter condition scores increasing to 3. These occasions suggested that additional corrective actions may have been needed for these situations (e.g. changes in ventilation).

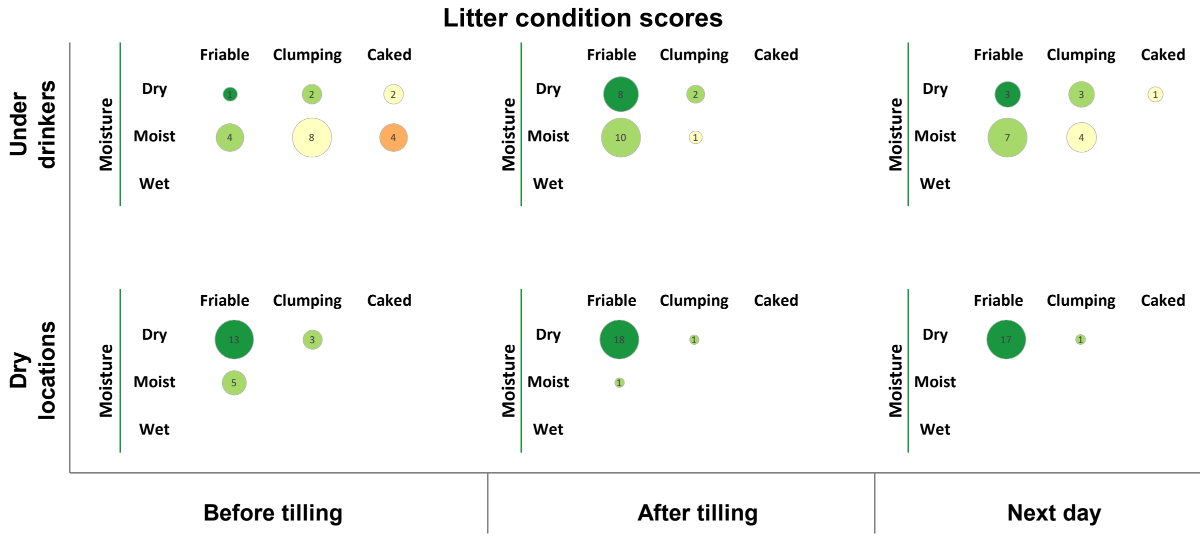


Figure 36. Bubble charts showing the frequency distribution of litter moisture, friability and overall condition scores for the flux chamber sampling points before and after tilling and on the day after tilling. Bigger bubbles represent higher frequency. Refer to Figure 22 for the scoring matrix.

In-shed ammonia concentrations

Ammonia concentration data from the farms were grouped by litter tilling day and the sample timing around each tilling event (Figure 37). Concentrations from the sensors were treated as independent values (rather than averaging them together) to show the variability in ammonia exposure in different parts of the shed.

In-shed ammonia concentrations fluctuated diurnally, independently from tilling events, with the highest daily concentrations tending to occur between midnight and 09:00 (presented in the time-series records of ammonia concentration in Appendix 3).

Ammonia concentration was observed to spike during tilling and for a short period afterwards. Within one hour after tilling, ammonia concentrations were below 15 ppm for the majority of tilling events, although the peak concentration measured on some occasions exceeded this value. After the first hour, ammonia concentrations continued to decline for another couple of hours and then tended to increase again, following the normal diurnal pattern as shed ventilation reduced in the evening.

The increase in ammonia concentrations, calculated as a ratio or multiplying factor relative to conditions immediately before tilling, were used to investigate if the scale of any increase was consistent between tilling events (Figure 38). This scaling factor was anticipated to give growers a way to estimate potential ammonia concentrations after tilling. They could then take action to increase ventilation more than normal if the ammonia concentration was expected to exceed 15 ppm. The calculated multiplying factors varied on each tilling day, but growers should expect tilling to increase the ammonia concentration by two to three times in the first few weeks, with the scaling factor increasing four to six times after the third week. While this increase was not linear, we suggest that it may be simplified by equating the multiplication factor with the week of the grow-out. For example, if it is week three (15–21 days) of the grow-out, ammonia concentration might be expected to triple during tilling. The grower could increase ventilation accordingly to manage the expected concentration.

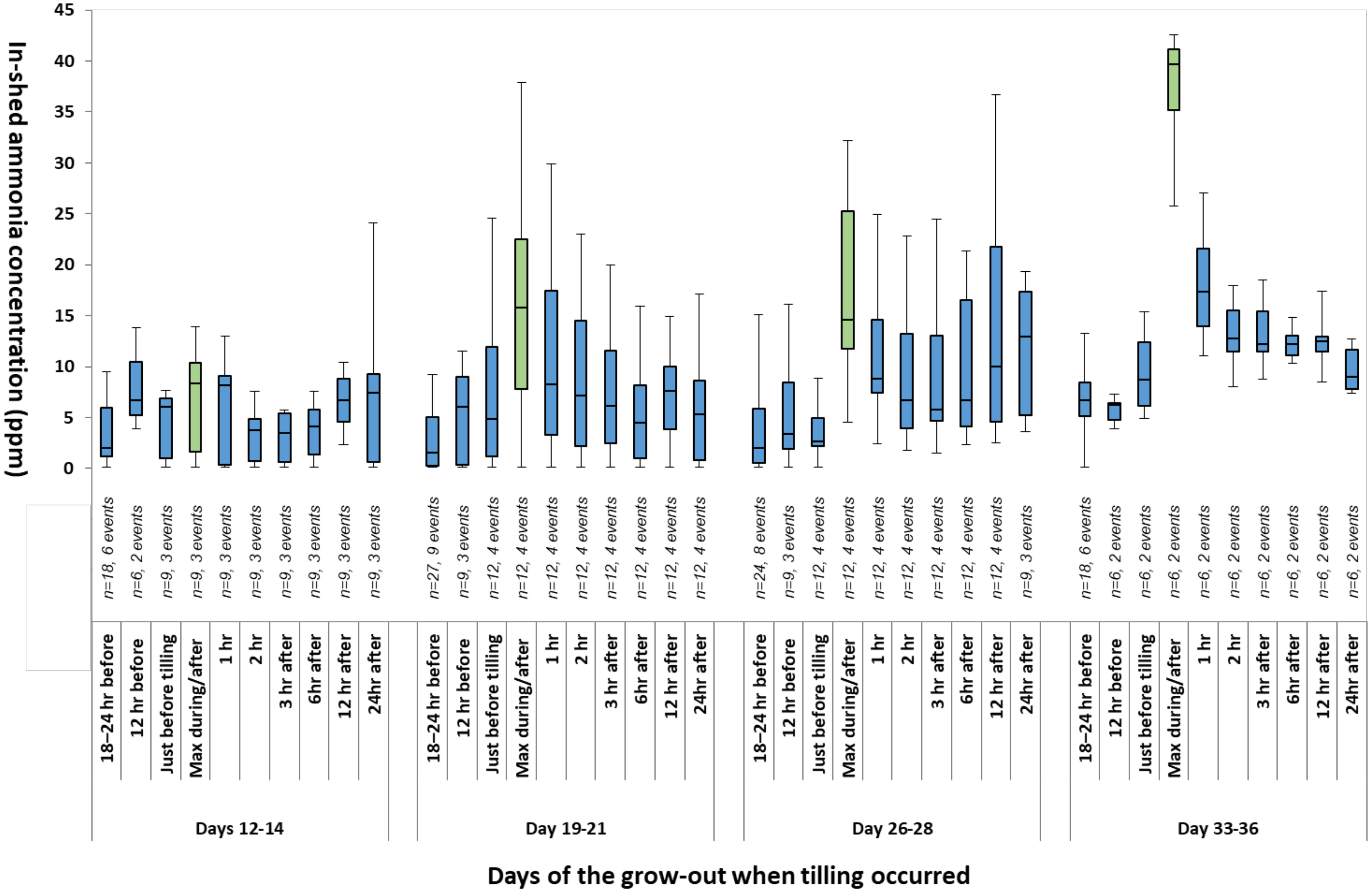


Figure 37. Boxplot of in-shed ammonia concentrations before, during and after litter tilling (three independent sensors per shed per event).

Boxes represent the 25th to 75th percentile; the line in the middle of the box is the median value (50th percentile); the whiskers represent the maximum and minimum values.

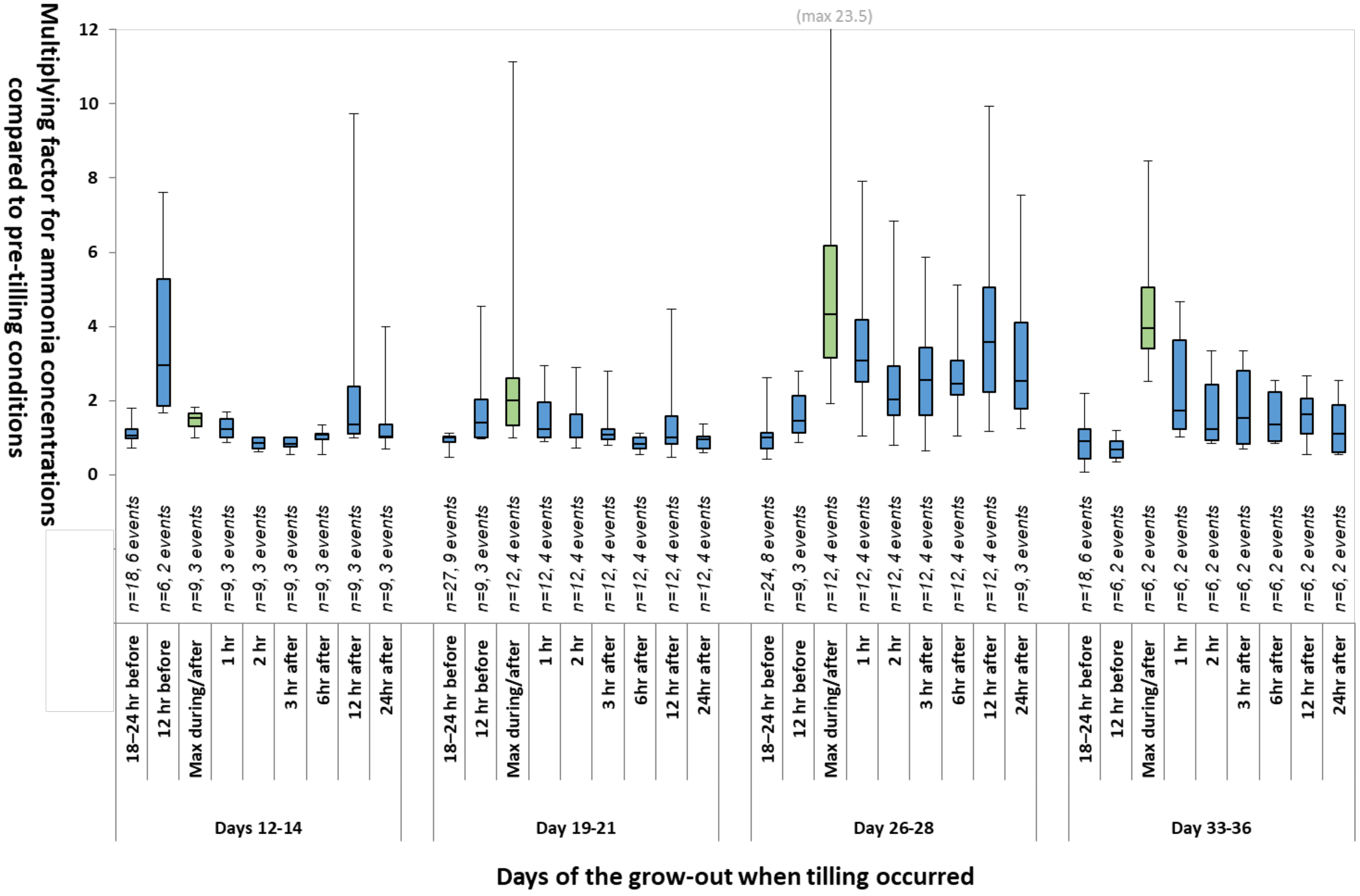


Figure 38. Boxplot of the multiplying factor (or ratio) to show the relative increase in ammonia concentrations compared to the concentration immediately before litter tilling.

Boxes represent the 25th to 75th percentile; the line in the middle of the box is the median value (50th percentile); the whiskers represent the maximum and minimum values.

Ammonia flux measurements from litter with flux chambers

The purpose of measuring ammonia emission rates directly from the litter was to improve our understanding of the effects of litter moisture, tilling, chicken age and different litter materials on ammonia production. Ammonia emission rates increased during the grow-out, with concentrations being significantly different ($P < 0.01$) between dry and wet (under the drinkers) sampling locations (Figure 39). Average ammonia emission rates for dry locations increased from 19.3 to 100.5 mg/m²/hr during the grow-out while wet locations increased from 71.3 to 211.2 mg/m²/hr. Litter moisture content was typically 18–25% for dry locations and 26–40% for wet locations (Figure 33).

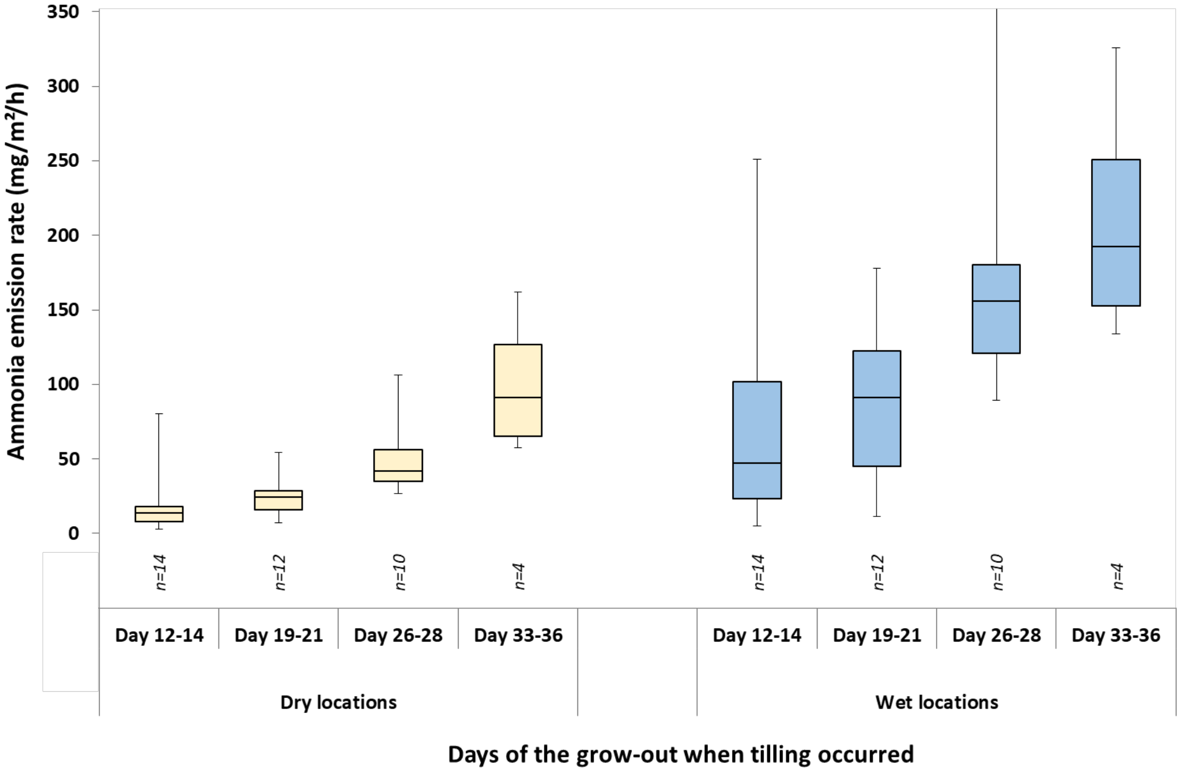


Figure 39. Boxplot of ammonia emission rates from the litter surface of dry and wet litter on litter tilling days. Data was grouped on each day to include emission rates from before litter tilling and the day after tilling.

Boxes represent the 25th to 75th percentile; the line in the middle of the box is the median value (50th percentile); and the whiskers represent the maximum and minimum values.

Ammonia emission rates were grouped by litter tilling day and sample timing (Figure 40). Ammonia emission rates from the litter were dominated by multiple two-way interactions:

- Age by sample timing around tilling ($P < 0.05$)
- Sample timing by litter location (dry or wet) ($P < 0.05$).

Ammonia emission rates from wet litter locations were 2.3–4.9 times high than dry litter. On average, emissions from wet litter were 3.8 times higher than dry litter based on the ratio between pairs of wet and dry samples collected at the same time and from nearby locations.

The ratio between emission rates from wet and dry litter reduced over the course of the grow-out. On days 12-14, emission rates from wet litter were 4.9 times higher than dry litter. This reduced during the grow-out and by day 36, when emissions from wet litter were only 2.3 times higher than dry litter.

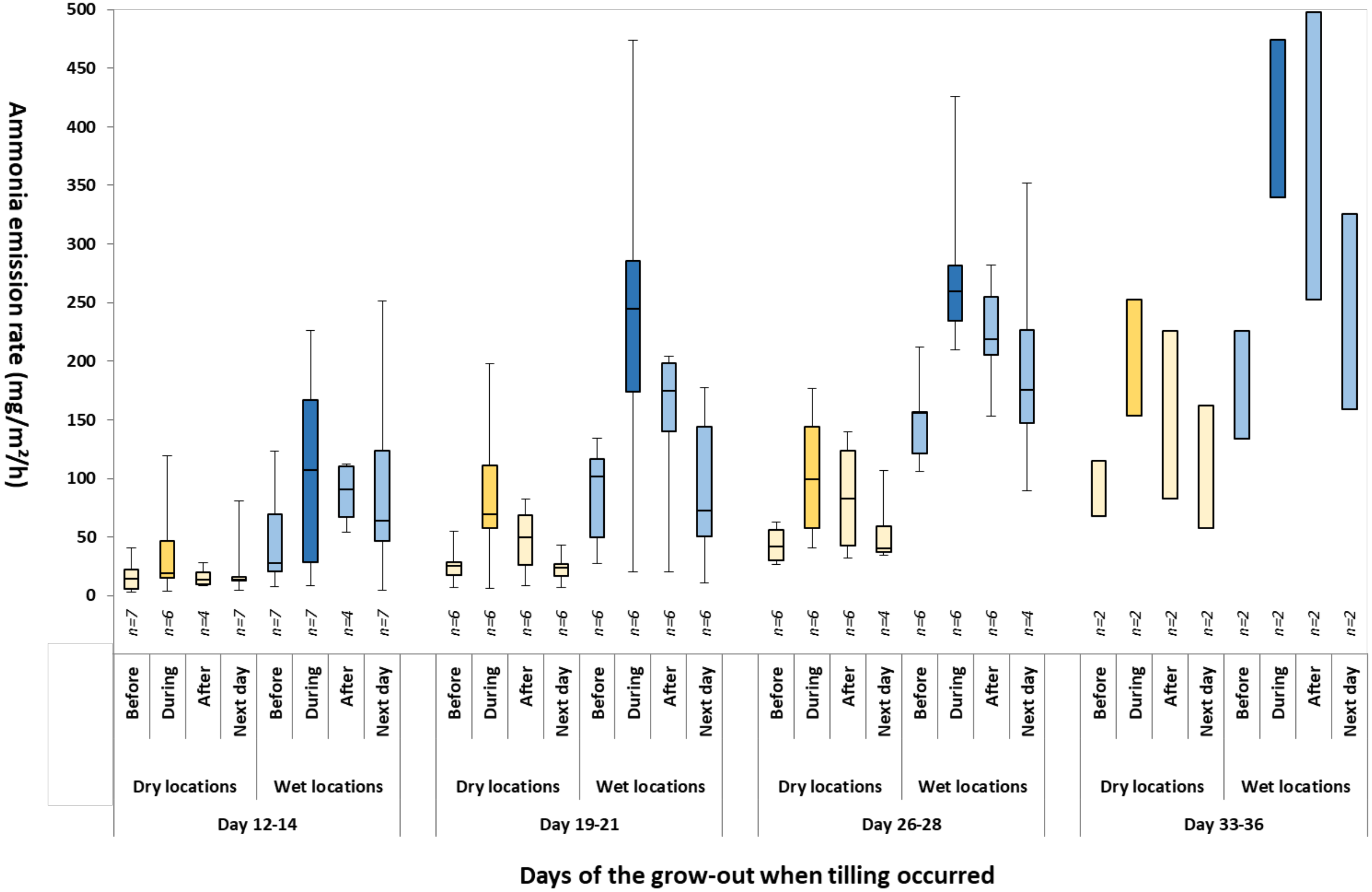


Figure 40. Boxplot of the ammonia emission rate (mg/m²/hour) from the litter surface before, during, 1.5-3 hours after and the day after tilling.

Notes: There was insufficient data for day 33-36 for boxplots – the bars show the spread of each data series. Boxes represent the 25th to 75th percentile; the line in the middle of the box is the median value (50th percentile); and the whiskers represent the maximum and minimum values.

Tilling significantly affected ammonia emission rates from the litter with the two-way interaction involving wet and dry sampling locations ($P < 0.05$):

- For dry locations, ammonia emission rates were:
    - 2.6 times higher during tilling, compared to before
    - 1.9 times higher 1.5–3 hours after tilling
    - 1.1 times higher the next day, 24 hours after tilling.
- For wet locations under the drinker lines, ammonia emission rates were:
    - 2.2 times higher during tilling, compared to before
    - 1.8 times higher 1.5–3 hours after tilling
    - 1.3 times higher the next day, 24 hours after tilling.

The relationship between litter moisture content and ammonia emission rates was non-linear. Peak ammonia emission rates occurred when litter moisture content was approximately 30% (Figure 41). This was consistent with Miles *et al.* (2008), who found that wet and caked areas had lower ammonia emissions than areas of moderate moisture content (25–30%).

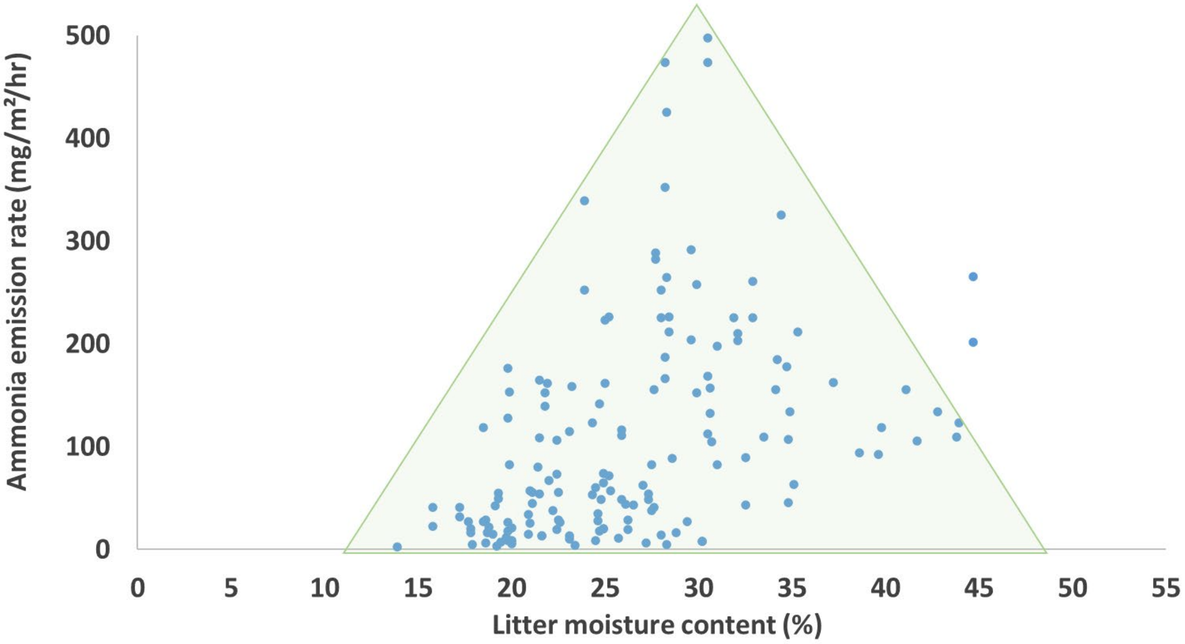


Figure 41. Relationship between ammonia emission rate and litter moisture content. The green triangle overlaying the data indicates that peak ammonia emission rates occurred at approximately 30% moisture content.

Ammonia emissions from poultry litter increased with the day of the grow-out, litter moisture content and tilling. Bedding materials also likely affected the potential for ammonia production, although it was challenging to identify the true effect of re-used litter within this project because sheds had only half of the floor covered with re-used litter. The statistical analysis suggested that bedding materials had a significant effect on ammonia emission rates ($P < 0.01$), and that the mean emission rate from re-used litter was 30% less than pine-based litter. It is suggested that this finding was affected by limited data involving re-used litter.

Observations during ammonia measurements revealed inconsistent emission rates from re-used litter. They could never be properly compared with pine-based litter, even within the same shed. This was because re-used litter was deeper, and has higher water holding capacity, resulting in it often being drier than pine-based litter. In sheds where re-used litter had high ammonia emissions, the grower had conducted minimal interventions with it. At other farms, however, ammonia emissions from re-used litter were lower and upon investigation, the grower explained that the litter had been tilled 4–6 times and was thoroughly dried between grow-outs. It is suggested, therefore, that emissions of ammonia from re-used litter are dependent on how it is prepared, prior to re-use.

In-shed carbon dioxide concentrations

Carbon dioxide measurements during tilling events demonstrated that tilling did not increase concentrations in the shed. Highest concentrations of carbon dioxide occurred at the start of the grow-out and during the night, 12 hours before and 12 hours after tilling (Figure 42 and Appendix 4). Higher concentrations 12 hours before tilling reinforce the independence of tilling operations to carbon dioxide. Carbon dioxide concentrations were consistently below the recommended maximum of 3,000 ppm (Aviagen Inc., 2018).

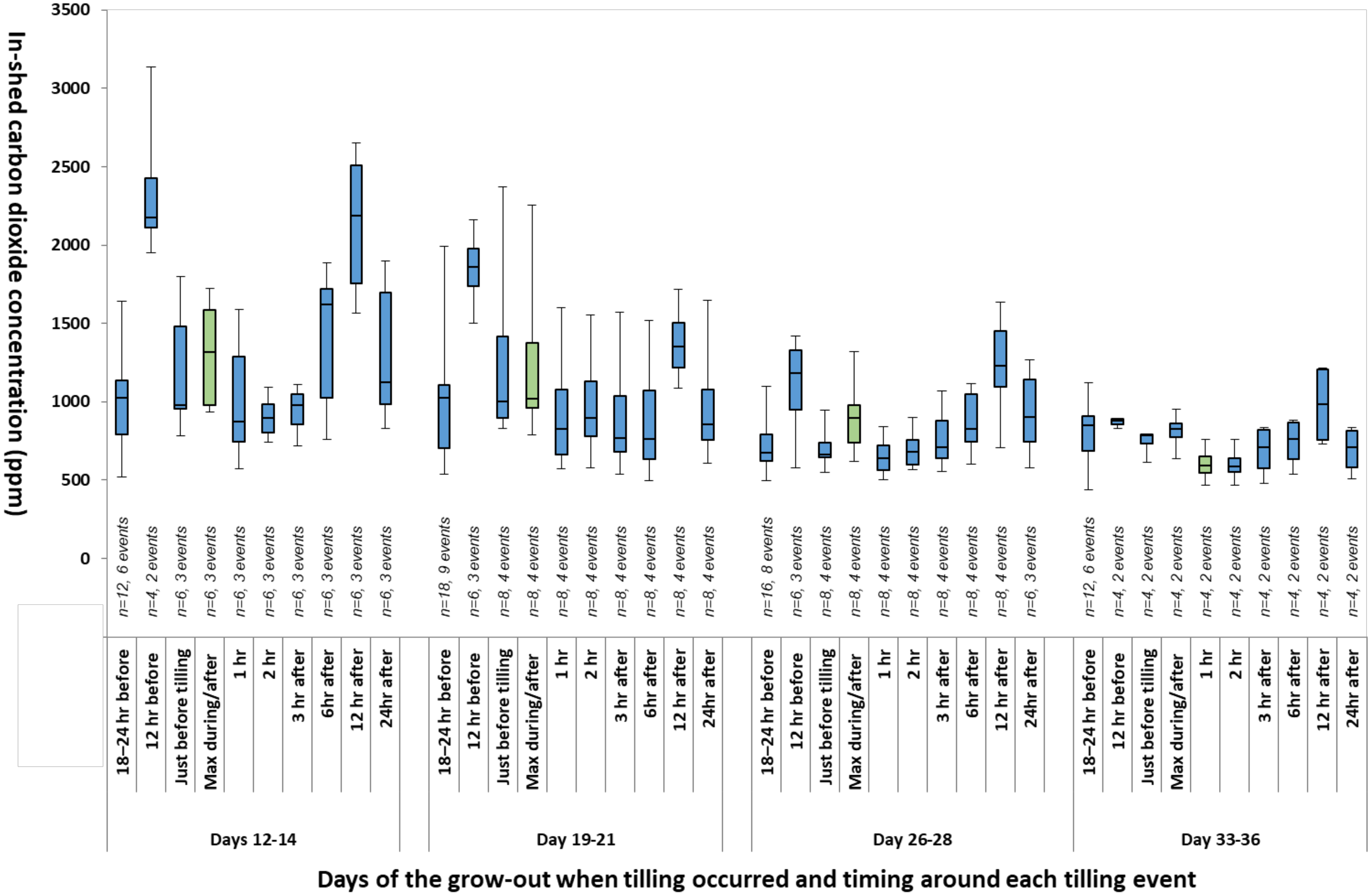


Figure 42. Boxplot of In-shed carbon dioxide concentrations before, during and after litter tilling (two independent sensors per shed per event). Boxes represent the 25th to 75th percentile; the line in the middle of the box is the median value (50th percentile); and the whiskers represent the maximum and minimum values.

Implications and recommendations regarding ammonia

Tilling is an effective management practice for breaking up cake and returning litter to a friable and ‘working’ state, so that fresh excreta can be incorporated into the litter by chicken activity. However, litter will not remain friable without effective ventilation, heating and other management practices. We observed that some tilling machinery did not always mix litter thoroughly across the width of the machine, therefore leaving a strip of moist litter, usually underneath drinkers. We also observed a variety of tilling patterns used by growers, and the reactions of the chickens to tilling.

There are opportunities for research to improve the operation of litter tilling machines. Chicken behavioural research may also be useful to improve tilling practices by ensuring they align with the natural behaviours of chickens as much as possible, to reduce risks and make tilling easier for growers.

Tilling accelerated evaporation for a short period of time, but also released ammonia that was trapped in the litter, causing a short-term spike in ammonia concentrations. In most cases, the spike started to reduce once tilling was complete and often dissipated in two to six hours. In some cases, ammonia concentration remained slightly elevated until the following day. Ammonia concentrations were occasionally observed to rise in the evening after tilling and persist until about 09:00 the next morning. We recommend that growers be aware that ammonia concentration may increase hours after tilling, and additional ventilation may be needed.

Ventilation was used by growers to manage ammonia concentrations in the shed, with the intention to keep levels below 15 ppm. Short periods with ammonia concentrations higher than 15 ppm were observed during tilling events, which suggested that more ventilation was required. We recommend that growers consider further increasing ventilation during tilling, if safe to do so, and not reducing it for two to six hours after tilling finishes. Some additional ventilation may even be required for 24 hours to keep ammonia below 15 ppm.

The actual amount of extra ventilation cannot be prescribed as there are many influencing factors. We recommend that growers be made aware of the following post-tilling ventilation requirements to keep the ammonia concentration below 15 ppm:

- At any chicken age, extra ventilation will be required if the ammonia concentration exceeds 15 ppm.
- Wet and caked litter will have a higher and more persistent ammonia spike compared to drier and more friable litter, which will affect the amount of extra ventilation required to keep ammonia concentration below 15 ppm.
- At 12 to 14 days, ammonia concentration barely increased during tilling, but some additional ventilation may be needed if it exceeds 15 ppm.
- At 19 to 28 days, ammonia concentrations exceeded 15 ppm during and after tilling:
    - During tilling and for up to two hours afterwards, ventilation needs to be greatly increased.
    - After two hours, the ventilation rate can be reduced if the concentration is below 15 ppm, but more ventilation than normal will likely be needed for up to 24 hours after tilling. Beware of ammonia concentration increasing during the night if ventilation automatically reduces during the evening as outside temperature drops.

- At 32 days or older, after small-bird flock thinning (where up to half the chickens are taken out of the shed for processing), ammonia concentrations exceeded 15 ppm during and after tilling:
    - Ventilation needs to be greatly increased during tilling and for approximately three to six hours afterwards.
    - After three to six hours, the ventilation rate can likely be reduced if the concentration is below 15 ppm, but more ventilation than normal may be needed for up to 24 hours after tilling.
    - Increasing ventilation is recommended during the first night and morning following tilling due to reduced heat production and associated lower ventilation rates in the shed following the small-bird flock thinning, in addition to cooler night-time conditions.

With additional ventilation needed for up to six hours after tilling to keep ammonia concentration below 15 ppm, we recommend that growers perform tilling during the mid to late morning, and ideally during fine weather. This will provide the biggest window of opportunity for increased ventilation during the afternoon to remove the maximum amount of ammonia and moisture from the litter. The potential for evaporation is much lower in the evening when temperature outside the shed drops and the relative humidity increases.

It was difficult to draw conclusions on the effect of re-used litter due to inconsistency in how it was prepared between grow-outs, and the interference of other litter types being used simultaneously in the sheds. In situations where low ammonia emission rates were measured from re-used litter (as compared with pine-based or hardwood-based litter in the same shed), the re-used litter had been prepared between grow-outs by tilling it 4–6 times and ensuring it was thoroughly dried before the next grow-out started. We recommend that growers re-using litter should prepare litter in this way to reduce risks associated with ammonia.

Measuring ammonia emission rates directly from the litter surface revealed that there are several factors contributing to emissions. Ammonia emissions increased during the grow-out, with litter moisture content and after tilling. Due to the multiplying effect, tilling wet litter later in a grow-out resulted in some of the highest observed ammonia emission rates. From the perspective of minimising ammonia emissions from litter, priority should be given to keeping litter as dry as possible, which will also minimise caking and keep the litter ‘working’. It is acknowledged that this is not always possible, but effective ventilation should be prioritised over litter tilling from the perspective of minimising risks related to ammonia.

While tilling the litter increased ammonia concentration in the shed, there was no effect on the concentration of carbon dioxide. Shed ventilation rates had the greatest effect on carbon dioxide concentrations. We recommend that growers continue to follow minimum ventilation guidelines.

Recommendations for growers about tilling and reducing risks relating to ammonia

Till litter on fine, warm days when relative humidity is low. Till litter in the mid to late morning to take advantage of the release of moisture from recently tilled litter.

Avoid litter tilling late in the afternoon when there will be only a short window of time to ventilate moisture and gases that are released. Evaporation is reduced at night and in the early morning.

Litter conditions before tilling will affect how much ammonia is released from the litter. If there is a large area of moist/wet/caked litter, then expect ammonia concentrations to increase and be prepared to ventilate at higher levels and for longer than you would if most of the litter in the shed is dry and friable.

Increase ventilation as much as possible during tilling, then continue ventilating at a higher level for at least 2-6 hours after tilling. After this time consider returning to automatic ventilation but increase the ventilation if ammonia concentration is above 15 ppm.

Be aware that ammonia concentration might increase during the first night after tilling when ventilation levels normally decrease. Increase ventilation to keep ammonia below 15 ppm.

Odour emissions during litter disturbance

Background

Concerns about the impacts of odour – real or perceived – have delayed approvals for new meat chicken farms and are therefore an obstacle to the growth and expansion of the industry. As such, odour has warranted substantial investment into research, development and extension (RD&E) from industry. Research studies have included the measurement of odour emission rates (OERs) from conventional and free-range farming systems using standard odour measurements (olfactometry) (Dunlop and Atzeni, 2020). Previous OER research has focused on 'normal' grow-out conditions, with the majority occurring prior to 2010. However, there is minimal data on or understanding of the effect of contemporary litter management operations and husbandry practices, including litter conditioning or bird pick-ups, on OERs.

In recent times, the odour impact assessment for some meat chicken farm developments have raised concerns about OERs during specific litter and production practices, especially litter tilling, litter clean-out and pick-ups. Additional OER data during these events were needed to improve understanding about emissions and to enable corrective actions to be developed if necessary.

The objective of this study was to measure odour emission rates at meat chicken farms during litter tilling, pick-ups and litter clean-out events.

Methods

Odour emission rate measurement

Odour samples were collected from sixteen meat chicken farms (Table 9) at different bird ages during litter tilling (n=8 events), chicken catching/pick-up (n=4) and litter heaping/cleanout events (where litter was removed from the shed at the end of the grow-out). They were collected before, during and after each event. Samples were collected from a treatment shed, where the event was taking place, and a neighbouring shed that was left undisturbed.

Odour samples were collected simultaneously from the treatment and control shed. Air samples were collected from a tunnel fan or the side-wall fan, depending on the ventilation program during collection period (Figure 43). Odour samples were collected into sample bags (15–20 L volume) inside 25 L drums. A vacuum pump was connected to the rigid sampling drums and used to draw odorous air into the bag using the 'lung' method. Each sample bag was pre-conditioned with the sample odour by filling and then emptying the bag just prior to the sample being collected. Sample collection took approximately four minutes, by drawing odorous air from the fan through an odour-free sample line.

Once a sample was collected, the drum was labelled and capped ready for transport to the olfactometry lab. All samples were analysed as quickly as possible following collection, with all samples analysed within 27 hours of collection, as required by the olfactometry standard. Samples were analysed using dynamic olfactometry to determine the odour concentration, which is measured in odour units (ou). The olfactometer was operated according to the Australian/New Zealand standard for olfactometry AS/NZS 4323.3-2001 (Standards Australia/Standards New Zealand, 2001).

OERs were calculated by multiplying odour concentration by the ventilation rate on a 'per 1,000 birds placed' basis. Shed ventilation rates were determined for each odour sample by recording the number of active fans, measuring shed static pressure and fan speed (RPM), and subsequently calculating ventilation rate from fan test data.

Table 9. Odour sampling program.

Odour focus	Details of each sampling scenario			Number of samples per scenario	Number of samples per focus
	Litter	Chicken age	Sample timing		
Litter tilling	Partial re-use and fresh bedding	26–40 days	Before tilling During tilling Three hours after tilling ends Six hours after tilling ends	8	64
Pick-ups	Partial re-use and fresh bedding	31–35 (small bird pick up age)	Before pick-up Before finish of pick-up During tilling of picked up area After pick-up – feed and drink lines back down and ‘back to normal’	8	32
	Partial re-use and fresh bedding	45–52 (large bird pick up age)	Before pick-up Halfway through pick-up Before finish of pick-up After pick-up	8	
Litter heaping/ clean-out	Partial re-use and fresh bedding	After grow-out (48–51 days)	Before pick-up Neighbouring shed with chickens Halfway through activity Before finish of activity	8	16
				Total number of odour samples	112

Figure 43. Odour sampling configuration and equipment used.

Ambient temperature and relative humidity, shed temperature, fan types (make, model and configuration), fan activity, shed static pressure, fan speed (RPM), event details and time were recorded at the time of each odour sample collection.

The air flow rate through each active fan was calculated using fan test data, and the static pressure measured in the shed using differential pressure meter (TSI Inc. DP-Calc model 8705 Shoreview MN, USA) at the time of sampling. This is because the air flow rate of a fan decreases as the static pressure of the shed becomes more negative. Fan test data was checked to ensure that the fans were tested with the same shutters, grills and cones as were fitted to the fans on the chicken sheds. Fan speed was measured using an optical tachometer, with the measured speed compared to the fan speed reported in fan tests. Flow rates were adjusted proportionally with the fan speed if they deviated by more than 5% from the test data.

Most of the farms had direct-drive fans, and their on-farm RPM closely aligned with the test data values. A few of the belt-driven fans deviated from the RPM in the test reports, most likely due to worn belts and sheaves. Finally, the shed ventilation rate was adjusted to standard conditions (0 °C, 101.3 kPa) as required by AS/NZS 4323.3 2001.

In-shed sensors used during in-shed ammonia measurements (described in the previous chapter) were placed in the treatment and control sheds to record the in-shed environment and to measure ammonia to investigate any potential relationships between odour and ammonia concentrations.

Litter sampling, moisture content analysis and scoring

Litter samples were collected for moisture content analysis, and litter conditions were scored using the *Litter guide – Daily litter condition assessment* methods described in the previous chapter for ammonia measurements.

Statistical analysis

General linear mixed models (GLMMs) were used to analyse the data using restricted maximum likelihood (REML) in Genstat (2022). The normal distribution with the identity link function was adopted, and residual plots were used to check the assumptions of homogeneous variances and low skewness. The fixed effects were:

- Treatment vs control
- Chicken age (day of the grow-out)
- Sample timing (around the tilling, pick-up or cleanout events)
- Litter type (fresh or re-used).

Two-way and three-way interactions were also analysed for significance. Only tilling events were analysed because pick-ups and litter cleanout had insufficient data.

Results and discussion

Litter moisture content and scores

Litter scores showed that most of the litter in the sheds before tilling was dry or moist and its friability was most frequently scored as friable or clumping, although some cake was found in the treatment sheds (Figure 44). Most caked litter was found under the drinker lines in both the control and treatment sheds. Following tilling, all caked litter in the treatment shed was broken up and returned to friable or clumping litter, while litter conditions were effectively unchanged in the control (untilled) shed and most of the ‘moist and caked’ and ‘wet and caked’ litter remained. The only statistically significant change due to tilling was the friability score in the wet litter (*P* = 0.05).

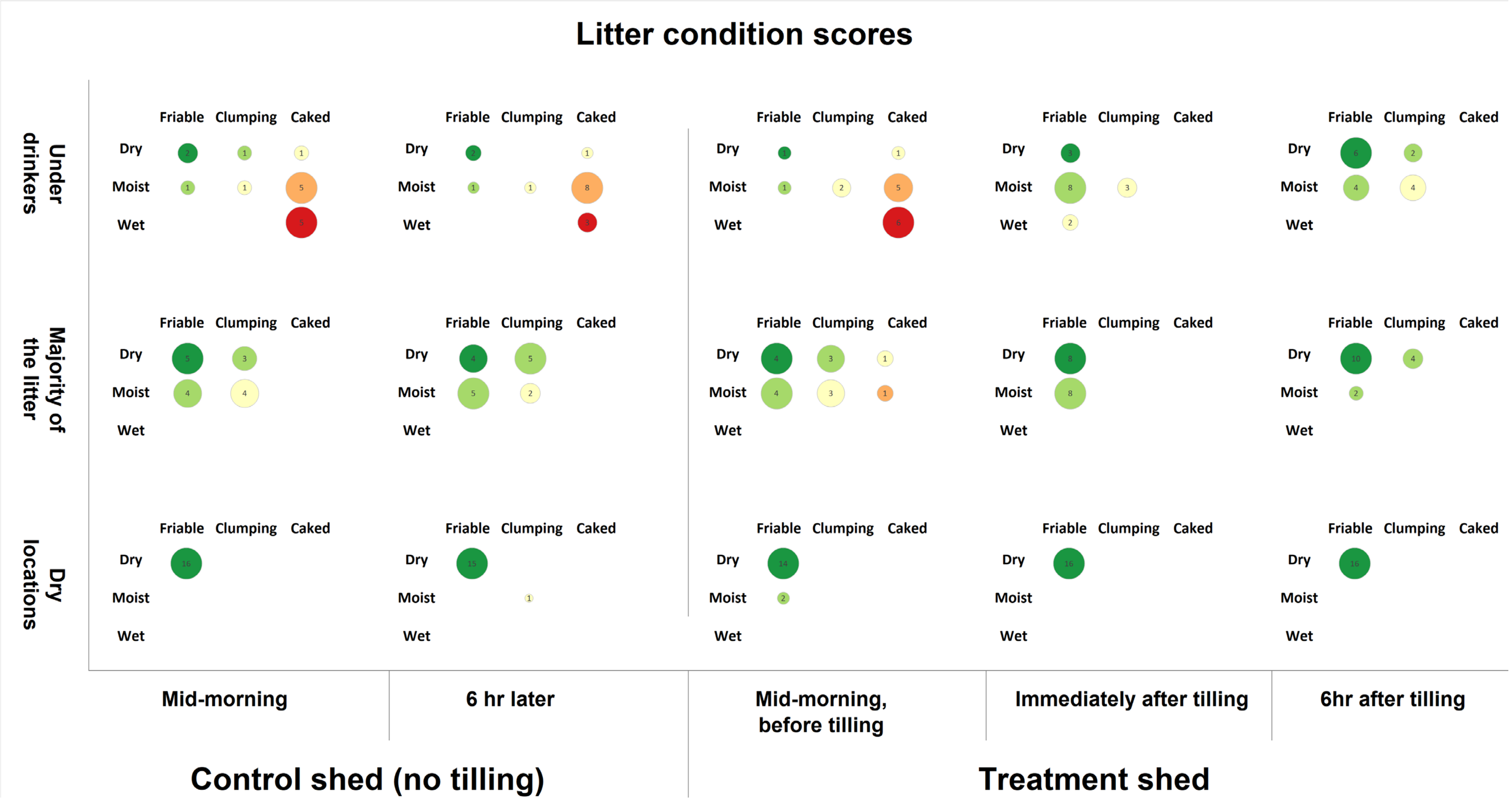


Figure 44. Bubble charts showing the frequency distribution of litter moisture, friability and overall condition scores at time points before tilling, immediately after tilling, and six hours after tilling. Bigger bubbles represent higher frequency. Refer to Figure 22 for the scoring matrix.

In the treatment shed, the moisture content was numerically lower six hours after litter tilling (Figure 45), but the difference was not significant. Most of the litter in the treatment shed, including the wet locations, was about five percentage points lower in litter moisture content following tilling. There was no change in litter moisture content in the control (untilled) shed.

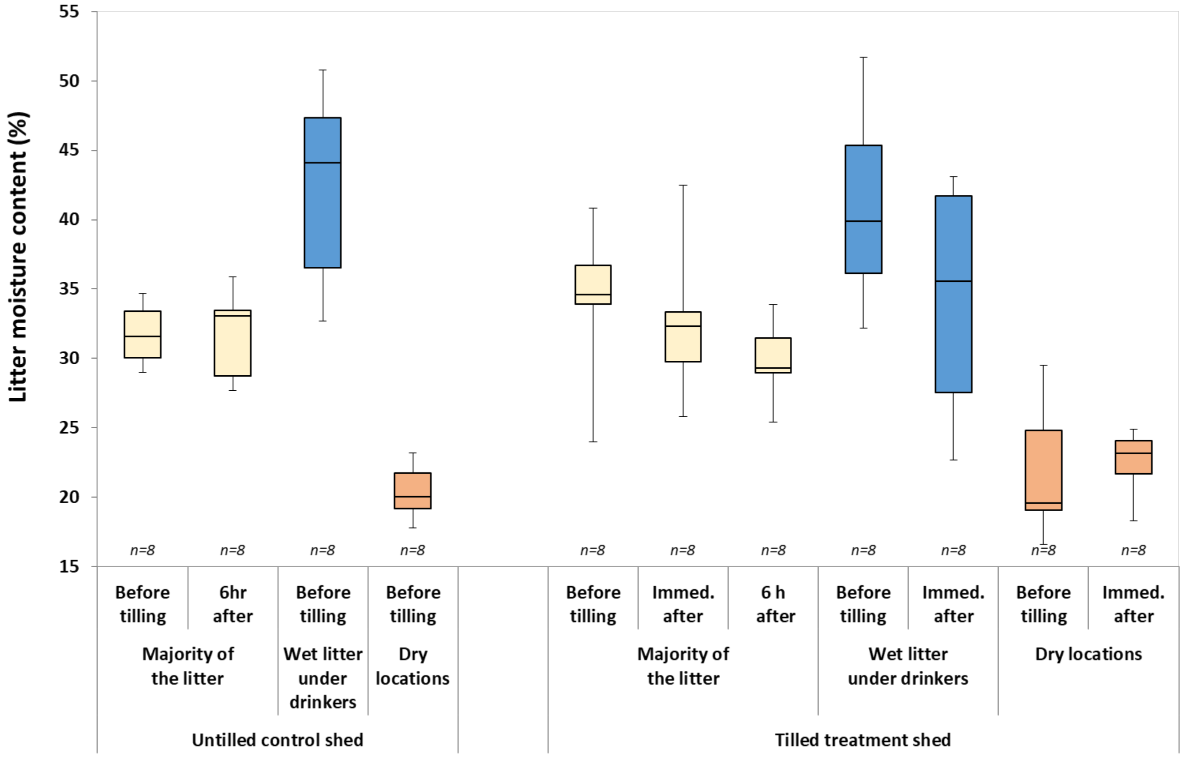


Figure 45. Boxplot of litter moisture content throughout the sheds at time points before tilling, immediately after tilling and six hours after tilling.

Boxes represent the 25th to 75th percentile; the line in the middle of the box is the median value (50th percentile); and the whiskers represent the maximum and minimum values.

Odour emission rates during tilling

OERs were highly variable (Figure 46), which was expected due to the dynamic nature of the scenarios being investigated. Tilling, pick-ups and litter clean-out events were conducted within timeframes lasting 0.5 to 4 hours, during which time there were considerable changes occurring with ventilation, the litter and/or the flock, and these are recognised as dominant factors that affect OER.

OERs measured in this project were compared with previous research (Dunlop *et al.*, 2011) to identify any considerable changes (Figure 47). Only the OER values unaffected by tilling were compared to the previous data because they represented similar environmental and production conditions. OERs unaffected by tilling included those measured from the control sheds, and those measured before tilling in the treatment sheds.

Visual comparisons were made about the general scale of OERs measured from the current and historical time periods. Each value represents specific production conditions, which makes comparing data sample-by-sample and day-by-day inappropriate. Based on this visual comparison, the overall scale of OERs have not changed since the earlier research; however, the previous odour measurements were undertaken earlier in the day, when ventilation was normally lower. Consequently, the OERs measured in this project after ventilation had started ‘ramping up’ would be expected to be higher than if they had been measured much earlier in the morning, the same time as the previous measurements.

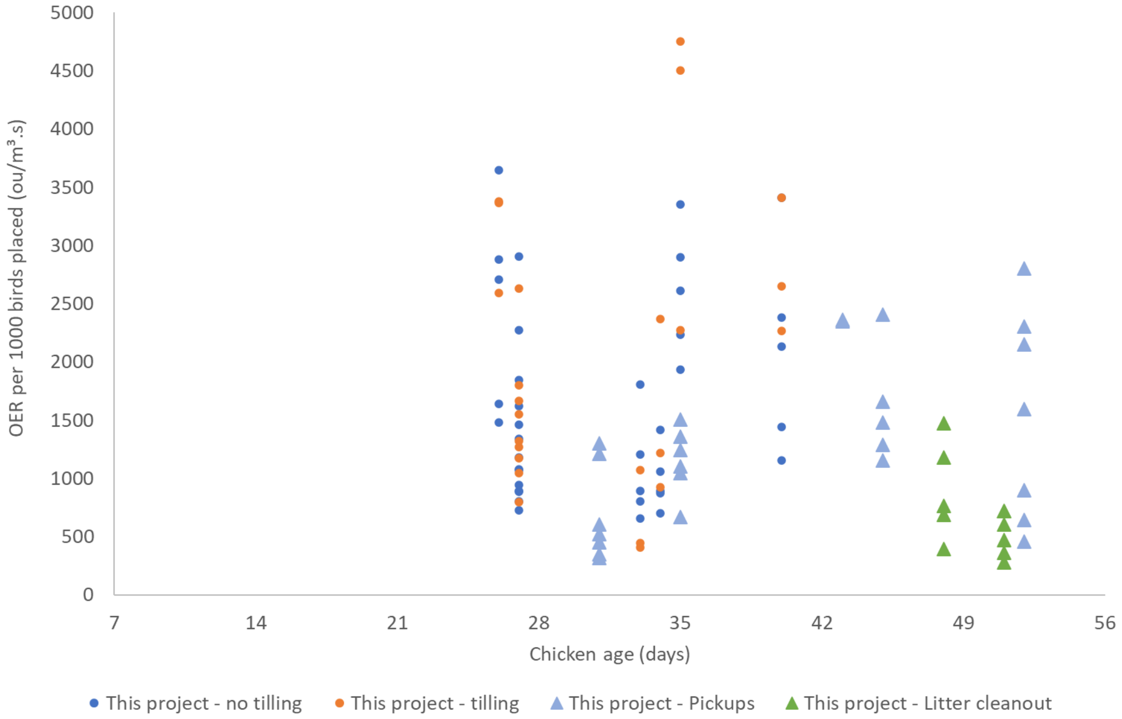


Figure 46. Odour emission rates (OERs, ou/s per 1000 birds placed) measured during tilling, pick-up and litter clean-out events during this project.

The ‘no tilling’ group referred to odour measurements collected during from sheds before they were tilled, or in untilled sheds.

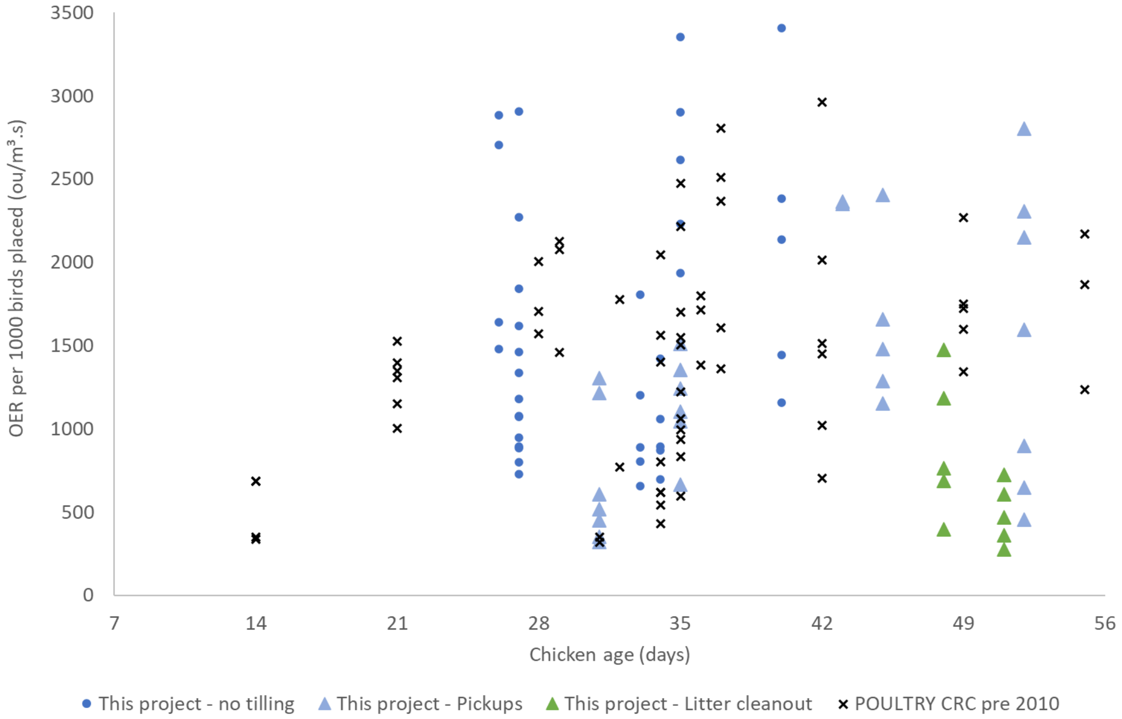


Figure 47. Historical odour emission rates (OERs, ou/s per 1,000 birds placed) from previous research (Dunlop *et al.*, 2011) for comparison to OERs measured during tilling, pick-up and litter clean-out events in this project.

The ‘no tilling’ group referred to odour measurements collected during from sheds before they were tilled, or in untilled sheds.

Odour emission rates during tilling were significantly affected by sample timing ($P < 0.05$) (Figure 48), but not by any two-way involving the treatment and control sheds. Litter in the control shed was not tilled, and the 'before', 'during' and 'after' tilling labels for control sheds simply indicate that the samples were collected at the same time as the comparison samples in the treatment shed. The OER increased significantly in both sheds during litter tilling in the treatment shed. It is suggested, based on previous experiences with OERs from poultry sheds, that the increase seen in the control shed was most likely related to the normal increase in ventilation that occurs each morning as temperatures rise. After three hours, the control shed still had a significantly higher OER, whereas in the treatment shed, the OER was only numerically higher than the before-tilling OER. By six hours after tilling finished, the OER was not significantly different than before tilling in either shed.

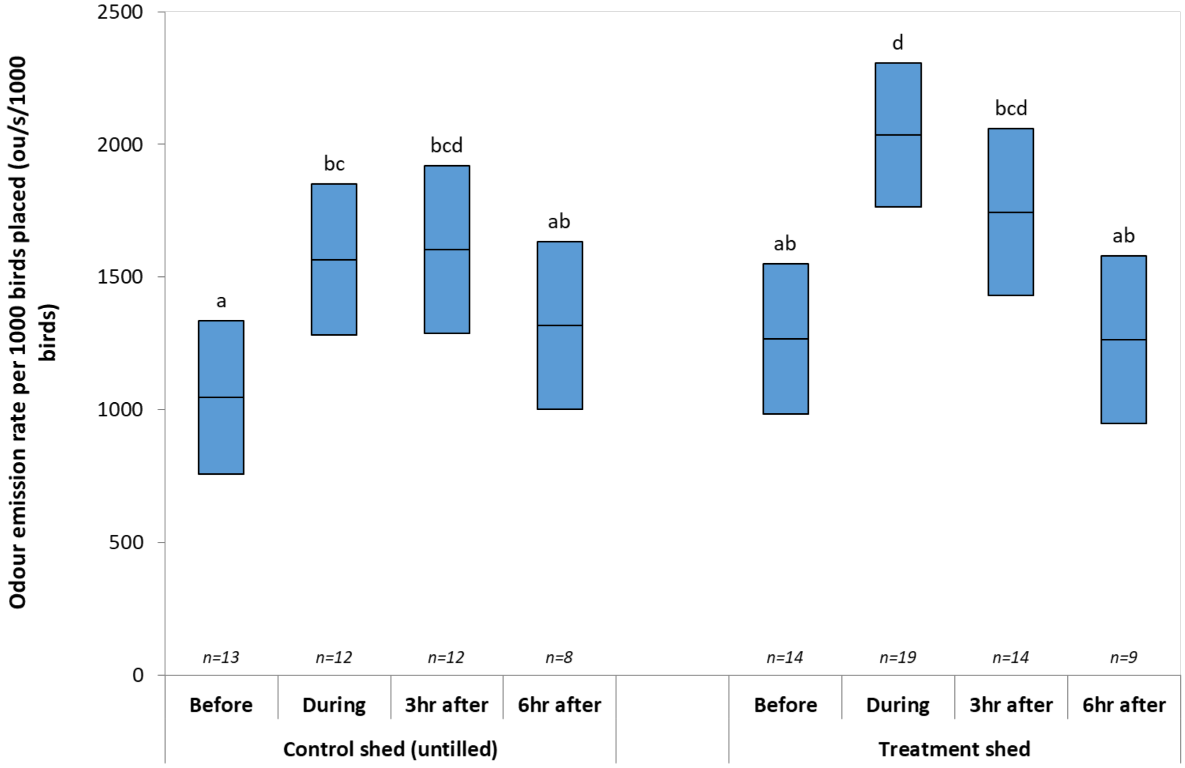


Figure 48. Odour emission rates during tilling events from the control and treatment sheds grouped by sample timing. Each bar represents the mean ± standard errors. Labels indicate significant differences ($P < 0.05$)

To further explore the effect of OER patterns before and after tilling, ratios to the 'before tilling' values were calculated (Figure 49). These ratios showed that there was a significant increase in the OER in the treatment shed during tilling whereas there was only a numerical increase in the OER in the control shed. After three hours, the increase in the OER in the control shed was significantly different compared to before tilling, while in the treatment shed, the increase in the OER was no longer significant.

The increase in the OER in treatment sheds was compared relative to the control sheds. This revealed that tilling contributed to a 20% increase relative to the normal daily increase in the OER that was measured in the control sheds. Any increase in the OER dissipated quickly and there were no numerical or statistical differences between the treatment and control sheds three hours after the tilling, pick-up or clean-out were finished. The OER in the treatment sheds six hours after tilling was lower than in the control shed, even though the OER was slightly higher in the treatment shed before tilling.

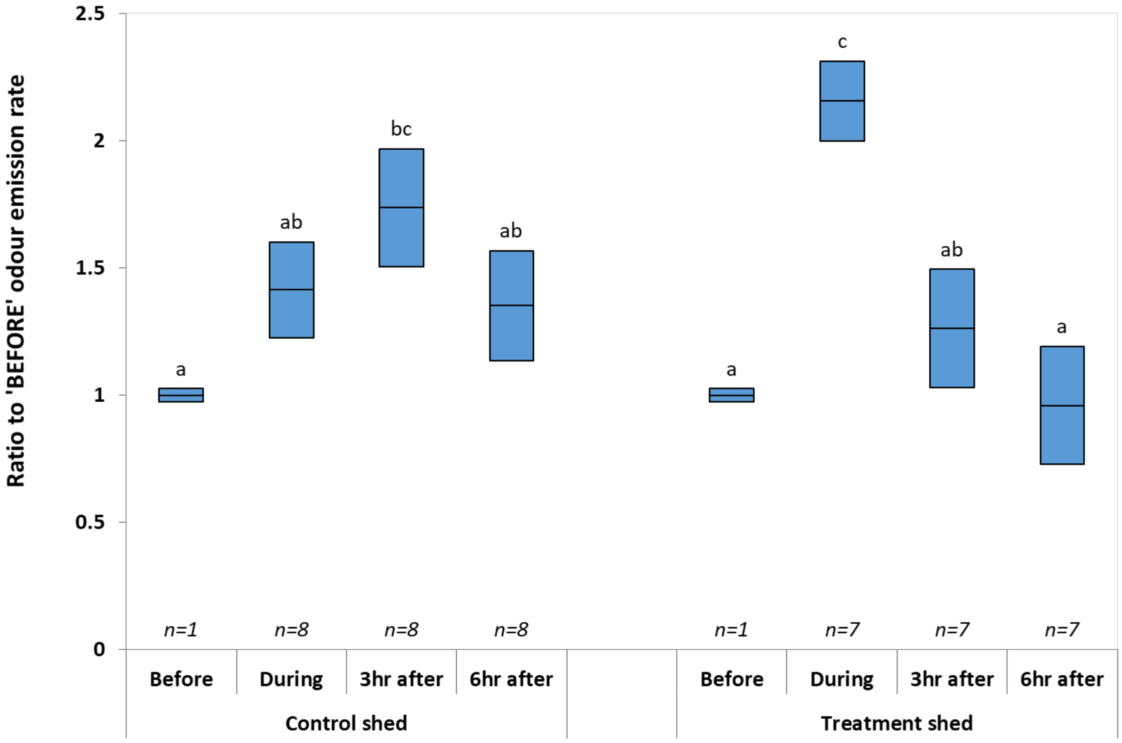


Figure 49. Odour emission rate (OER) ratios during tilling events of measured values to the respective 'before tilling' OER in the control and treatment sheds grouped by sample timing. Each bar represents the mean ± standard errors. Labels indicate significant differences (*P* < 0.05)

Odour emission rates during pick-ups and litter clean-outs

Odour emission rate increased during pick-up events in the treatment sheds (Figure 50) and then reduced once the pick-up was finished. On average, OERs during pick-ups were approximately 2.2 times higher than before the pick-up. It is suggested that the observed increases in the OER were primarily influenced by increasing ventilation rate during pick-up, which is essential for the chickens and pick-up workers. After pick-up had finished and the number of chickens was reduced and ventilation returned to normal levels, the OER in the treatment shed was lower than in the control shed.

Pick-up events included in this study occurred at night or very early in the morning when ambient temperature was relatively constant and close to the minimum daily temperature. Consequently, ventilation had not started to increase the way it normally would due to temperatures increasing during the day. Consequently, OERs did not increase in the control shed at the time of the pick-up in the same way that OERs in the untilled control sheds increased during tilling events.

OERs measured during litter clean-out operations showed they increased while machinery was operating in the shed and disturbing the litter (Figure 51). OERs during litter clean-out were always lower than a neighbouring control shed that still had chickens present. These observations were based on limited sample numbers but agree with previous research (Dunlop *et al.*, 2011) where OERs were found to be significantly reduced once chickens were removed from the shed.

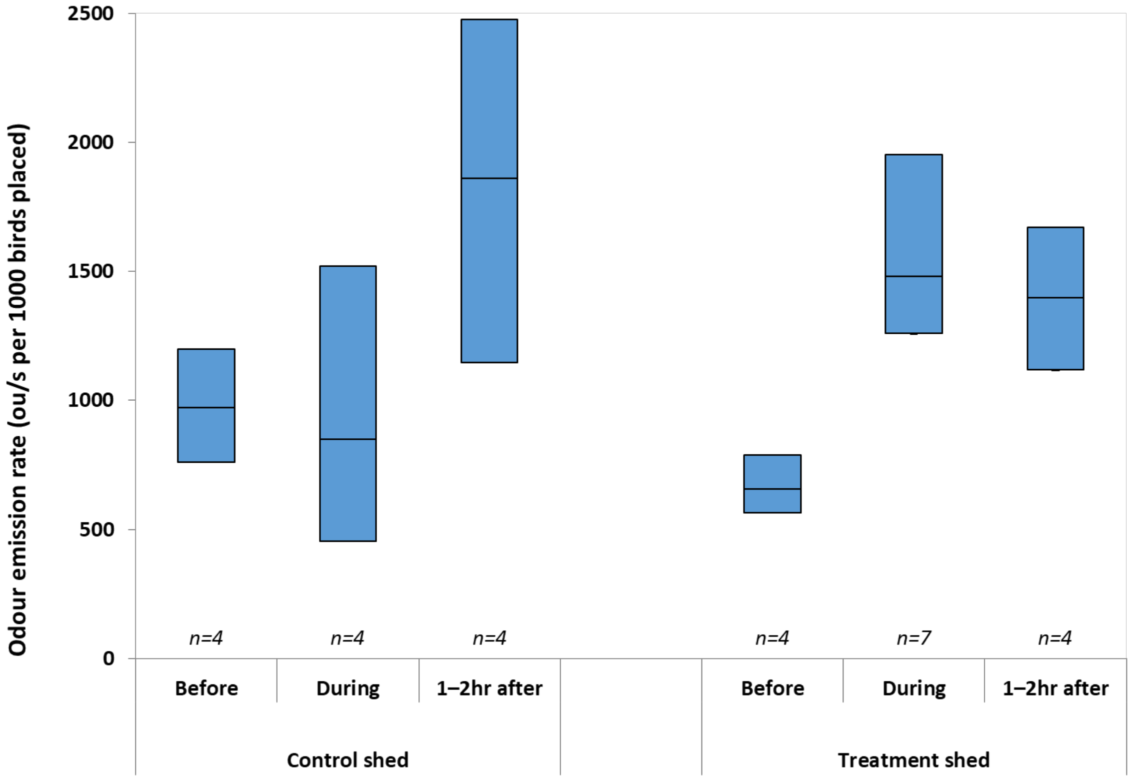


Figure 50. Odour emission rates during pick-up events from the control and treatment sheds grouped by sample timing.

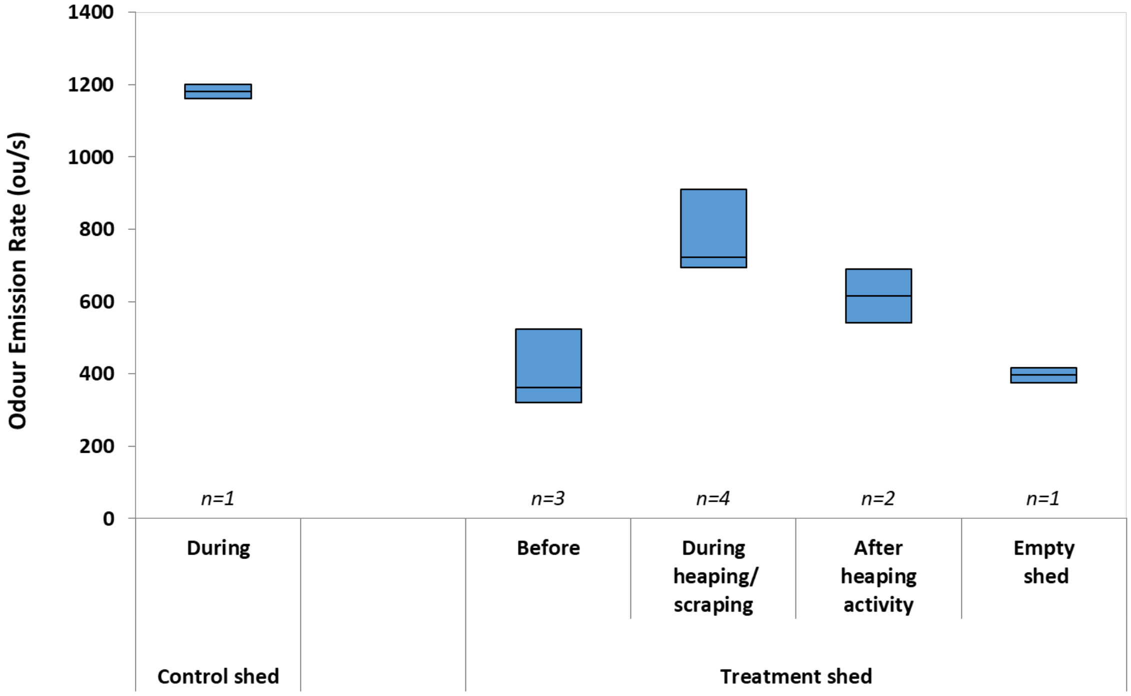


Figure 51. Odour emission rates during litter clean-out events from the control and treatment sheds grouped by sample timing.

Comparison of ammonia and odour

Ammonia concentrations measured at exhaust fans were compared to odour concentrations, but no relationships were found (data not shown). This was not surprising due to different chemical-microbial processes being responsible for producing ammonia and the range of odorous chemicals that contribute to odour (Dunlop *et al.*, 2016).

Ammonia concentrations were analysed and were found to be dominated by a significant two-way interaction between the sheds (treatment vs control) and timing of the sample (before, during and after tilling) ($P < 0.01$). In the treatment shed, ammonia concentration was significantly increased during tilling, but was not significantly or numerically different after three hours compared to the pre-tilling value (Figure 52). This aligns with the ammonia measurements discussed in the previous chapter and the ammonia concentrations relative to tilling are comparable to ammonia emission measured after day 26 of the grow-out (Figure 37). As discussed earlier, additional ventilation may have been needed during these tilling events to keep ammonia concentration below 15 ppm.

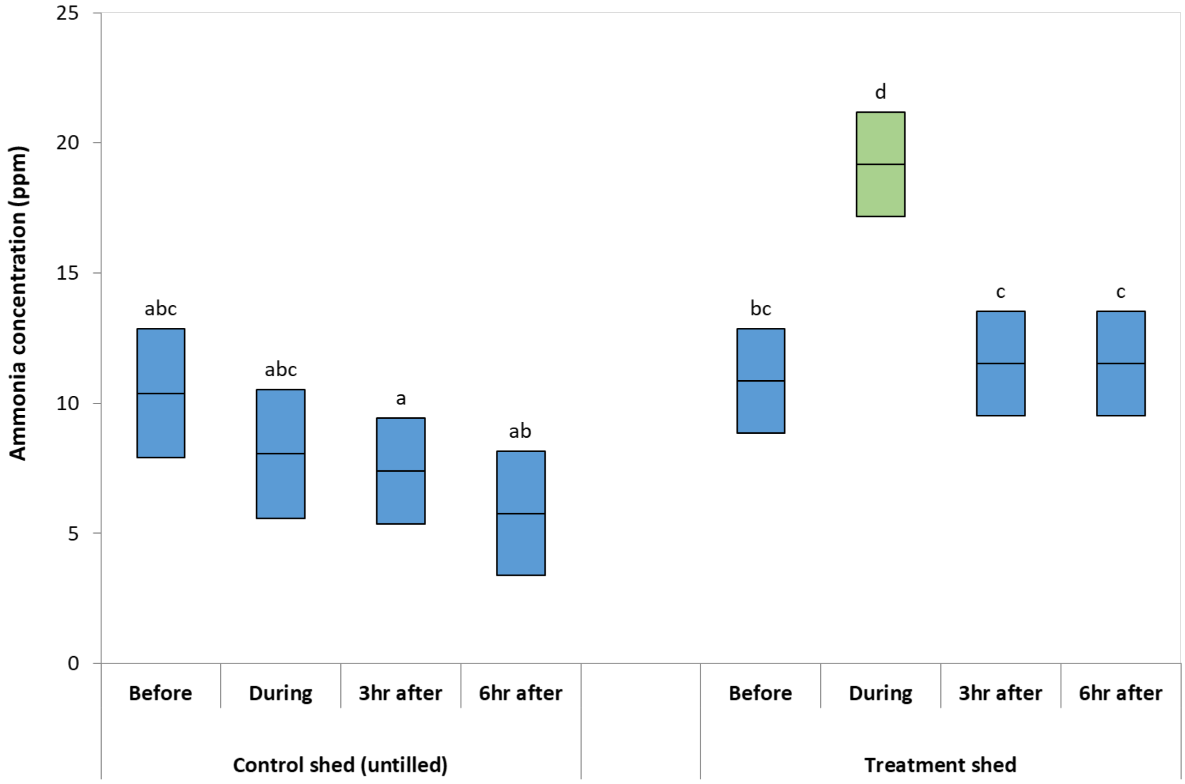


Figure 52. In-shed ammonia concentrations during tilling events from the control and treatment sheds grouped by sample timing. Each bar represents the mean ± standard errors. Labels indicate significant differences ($P < 0.01$)

Implications and recommendations regarding odour

Based on a visual comparison of OERs measured under similar conditions, the overall scale of OERs has not changed since earlier research measurements of OERs were taken prior to 2010. However, measurements of OERs in previous research were undertaken earlier in the morning before ventilation had increased with daily temperature. This may mean that the OERs measured in this study may have been inflated relative to the previous research. Odour modellers should not change from their current methods to predict the OER based on the findings of this research.

The OER was found to increase during tilling by about 20% relative to an untilled shed. By three hours after tilling, OERs from tilled sheds were comparable to OERs from untilled sheds. By six hours after tilling, there were indications OERs may be even lower after tilling compared to an untilled shed.

The purpose of measuring and assessing odour from meat chicken sheds is to reduce the potential for odour impacts on neighbours. Odour impacts are influenced not only by the OER from a source, but how the odour disperses in the environment between the source and a receptor. Litter tilling is a planned activity that, according to the industry survey, is mostly performed from mid-morning to noon. During this time of the day (excluding when there is inclement weather), environmental dispersion of odour is usually at its peak. It is suggested that a 20% increase in the OER is unlikely to increase the potential for odour impacts, especially if it is performed when the odour will rapidly disperse.

The OER was observed to increase during pick-up and litter clean-out events along with increases in shed ventilation rate and machinery disturbing the litter. These events represent a non-reversible change of conditions in the shed. Once the pick-up or litter clean-out was completed, the OER from the shed was lower than an undisturbed neighbouring shed.

There were no relationships found between odour and ammonia. In a similar way to the ammonia-focused studies, in-shed ammonia concentration increased during litter tilling, but by three hours after tilling had returned to the pre-tilling value. Ventilation should be increased during and shortly after tilling if the concentration is higher than 15 ppm.

Recommendations for tilling to minimise odour impacts

Till litter on fine, warm days when relative humidity is low. Till litter in the mid to late morning to take advantage of the release of moisture from recently tilled litter.

Avoid litter tilling late in the afternoon when there will be only a short window of time to ventilate moisture and gases that are released.

Avoid litter conditioning at night and in the early morning when the potential for evaporation is lower and there is usually a higher risk of causing odour impacts.

Avoid tilling at when it is less suitable to increase ventilation rate to exhaust released gases and moisture, such as when it is very cold or wet outside (depends on the time of the grow-out).

Models to simulate litter moisture content and management practices

Background

Managing litter moisture is important because it affects the insulating, cushioning and water/manure absorbing properties of litter. Moisture content affects the potential for ammonia, odour and dust emissions. Water additions, evaporation and the resulting changes to moisture content are very dynamic, complex and inter-related processes that are affected by multiple factors. From the perspective of researching and developing litter management practices, it was believed there would be many benefits to modelling these and their effect on moisture content. A computational model would allow the simulation of litter management practices and technologies on litter conditions under a variety of production, regional climate and weather conditions.

Previous investigations have increased our understanding of litter moisture content as affected by water holding properties, water additions and evaporation (Dunlop *et al.*, 2015). However, the combined effect of these factors on the litter moisture content throughout a grow-out have remained unknown. With the aim of developing a litter moisture model, the following information has been drawn upon from previous investigations:

- Water holding properties are affected by the type of bedding material (e.g., sawdust, rice hulls, straw and re-used litter), litter depth and the manure content.

- The *volumetric water content* of litter (L/m^3, kg/m^3 or L/m^2 for a specified depth, for example 5 cm) will vary between different litter types and density of the litter even when the litter moisture content (%) is the same. Litter moisture content is calculated as the percentage of the *mass of water* contained in the litter (mass of water divided by the mass of the whole litter sample). In general, the denser the litter, the more water that litter will hold (L/m^3) for the same moisture content. In general, re-used litter is denser than bedding materials, hardwood is denser than pine and sawdust is denser than shavings.

- Chicken droppings are the greatest regular source of water addition to the litter and will contain different amounts of water depending on the feed (ingredients, nutrient formulation and energy content) as well as chicken age, thermal comfort and daily activity cycle (relating to lighting programs).

- Additional water will be added from condensation, water leaks, ground seepage and the drinkers. Water added to the litter from drinkers may be due to routine spillage while the chickens are drinking or due to leaks.

- Laboratory-based litter drying experiments have demonstrated that evaporation of water from the litter is affected by ventilation, temperature, relative humidity and the wetness of the litter. In general, evaporation increases with higher air temperature, lower relative humidity, higher airspeed and wetter litter. However, it is challenging to re-create the complex and dynamically changing conditions experienced within a poultry shed under controlled laboratory conditions. Some evaporation theory is needed to extend the experimental results to a wider range of temperature, relative humidity and airspeed conditions.

One barrier to successfully modelling litter moisture content has been a lack of detailed and frequent data (hourly or sub-hourly) of the internal and external environmental conditions, ventilation activity and production parameters of a poultry shed. Recent advancements in environmental controllers for poultry sheds allow for the recording of fan activity, ventilation rate as well as internal and ambient temperature and relative humidity (where these controllers and appropriate sensors are installed).

While there has been an increase in knowledge and data collected on water additions and evaporation from litter, there are still knowledge gaps and assumptions that need to be made about:

- The effect of litter disturbance by the birds or machinery on evaporation rate.
- The ratio between the amount of water excreted or used for cooling (by respiration) depending on the thermal comfort of the chickens. Thermal comfort is affected by temperature, relative humidity and air-speed combinations at different stages of growth.
- Spillage and leaks from drinkers to the litter.
- Condensation forming in the litter or forming on shed surfaces and dripping onto the litter.
- Airspeed at the litter surface, especially during low ventilation conditions and when air is entering the poultry shed through the side-wall mini-vents.

Objectives

The objective of creating computational models was to enable the prediction of litter moisture content on each hour and day of a grow-out using a combination of real-word and theoretical production inputs, ventilation data, weather data and experimentally derived formulas for litter evaporation processes. In this project, we aimed to create models and validate their predictions, if possible, using experimental measurements in meat chicken sheds.

With the strong focus on litter management practices in this project, a further objective was to simulate different management strategies such as:

- Litter tilling
- Circulation fan systems
- Litter pre-heating and drying (before chick placement).

The aim of modelling these strategies was to evaluate them under otherwise constant conditions and test different application strategies. For example, within a model, it would be beneficial to test different frequencies for litter tilling, such as weekly compared to fortnightly.

Methods

Previous research has provided methods to estimate the addition of water to litter from chicken excretion as well as evaporation from litter (Dunlop *et al.*, 2015). Estimating the amount of water in droppings was based on published daily feed intake values and a water:feed intake ratio ranging from approximately 1.6 to 2.0. Evaporation estimates were derived from laboratory-based experiments under a limited number of controlled conditions, which requires the application of evaporation theory to extend the theoretical calculations. While these provided a basis for calculating the water balance in chicken litter, some assumptions also needed to be made to address unknowns. Assumptions and unknowns may affect the accuracy of modelling and require a ‘correction factor’ to improve predictions and ensure the modelled values reflected real-life litter conditions.

Assumptions for water additions include:

- Commercial feed specifications and ingredients have similar digestibility and require the same water:feed intake ratio as published nutrition specifications.
- Under thermal-neutral conditions, the amount of water available for excretion is 50%, with the other 50% used by the chicken for temperature regulation (evaporation from their lungs). The amount available for excretion can vary from 20-80% if the chickens are too warm or too cold, respectively.
- Chickens are always thermo-neutral.
- Chickens are evenly distributed within the shed.
- Chicken water consumption varies hourly, closely associated with lighting programs, and that chickens excrete water at approximately the same time as water intake, which is used to indicate chicken activity (there is limited data on the time between water intake and excretion, and the timing of metabolic water formation after consuming feed and subsequent excretion).
- Additions of water from condensation are minimal, as there is no data available to confirm otherwise.
- Additions of water from the drinkers are minimal. The moisture content values predicted by the models should be considered an estimate of 'average' conditions throughout the shed, and that litter underneath the drinker lines will be wetter than the average. This is supported by observations of litter conditions in meat chicken sheds.

Assumptions for evaporation include:

- Water evaporates evenly across the shed floor
- Evaporation rate is related to temperature, relative humidity and airspeed, which are averaged for the timing interval used in the model (i.e., hourly).
- Conditions in the shed are evenly distributed (i.e., the temperature and relative humidity measured by the sensors reflects the conditions at the litter surface).
- Airspeed at the litter surface during tunnel ventilation is calculated from the air flow rate through the ventilation fans divided by the aerodynamic cross-sectional area of the shed.
- The effects of chicken activity disturbing the litter surface (likely to increase evaporation) and the effect of chickens covering the litter while sitting (likely to reduce evaporation) are unknown and therefore not included in the model.
- Evaporation experiments have focused on friable litter and so evaporation models only apply to friable litter. Experiments have focused on friable litter due to litter being friable most of the time, and due to technical challenges trying to use caked samples during experiments.

At the start of this project, there was a lack of information or data available on some processes relating to water balance modelling and litter management activities, which required investigation or experimentation:

- The effect of litter tilling on water evaporation rates was unknown. Based on theory of emissions from porous materials, tilling the litter would increase water evaporation by bringing trapped water to the surface, opening pores in the litter and increasing the surface area for water evaporation (Dunlop *et al.*, 2016). Information was needed to quantify the increase and duration of water evaporation rates after tilling.

- Airspeed at the litter surface during side-vent ventilation was unknown.
- Airspeed at the litter surface when using circulation or stirring fans has not been measured in Australia but is reported in overseas research.

Models require validation to confirm that predicted values are an accurate estimate of conditions observed in real-world situations. Predictions from the litter moisture content model were compared to a small number of moisture content measurements at two meat chicken sheds where ventilation and on-site weather data were also able to be obtained and entered into the model. There were insufficient data points for meaningful statistical analysis and so the modelled and observed data were compared visually.

Results and discussion

Two different models were created during this investigation.

The first model calculated the reduction in litter moisture content due to different heating, ventilation and tilling strategies before placing day-old chickens. It is especially relevant for when wet bedding is delivered to a farm. This model combined experimentally determined evaporation rates and theoretical adjustments of evaporation rates for different combinations of temperature and relative humidity (based on local weather observation data). This model was not able to be validated with on-farm litter assessment.

The second model was created to calculate changes In litter moisture content using estimates of water added to the litter by the chickens and evaporation due to ventilation. The calculation interval selected for this model was one hour, which enabled estimation of litter moisture on every hour of a grow-out cycle (typically 52–56 days in length). This model used estimates of water excretion based on published daily feed intake data. Unlike the first model, this model used ventilation data collected from meat chicken sheds to provide real data on weather conditions, ventilation rates and in-shed conditions. Ventilation and weather data was obtained from two meat chicken sheds in South East Queensland where other project activities were being undertaken. Outputs from the model were compared to litter moisture content samples collected in each of the sheds. Litter samples were collected before and after litter tilling events.

Before developing the models, there was a need to fill knowledge gaps with litter drying processes including how litter tilling and airspeed during minimum ventilation affected evaporation rates. Some discrete investigations were undertaken to fill these knowledge gaps.

Collecting data to fill knowledge gaps with litter drying processes

Effect of litter tilling on evaporation rates

An experiment was carried out to measure the increase in evaporation rate (L/m^2/hr) due to litter being stirred. Litter samples (collected on days 30, 47 and 56 of a grow-out) were prepared at a range of moisture contents (15%, 30% and 45%) and placed into small cups, which were put into one of four chambers where airspeed could be controlled at either 0.5, 1.0, 1.5 or 2 m/s (Figure 53).

The four wind chambers were placed into a temperature and humidity-controlled cabinet that was set at 25 °C and 50% relative humidity and later at 35 °C and 50% relative humidity in a subsequent experiment. This equipment and experimental procedure has been previously described (Dunlop *et al.*, 2015).

Figure 53. Wind chamber used to provide constant airspeed (0.5, 1.0, 1.5 or 2.0 m/s) at the surface of litter samples.

In the current experiment, samples were divided into two groups: ‘stirred’ and ‘unstirred’.

- Unstirred samples were put into the cups at the start of the experiment (which inherently caused mixing/stirring of the sample) but were not disturbed again for the duration of the experiment. Each experiment lasted 24 hours.
- Stirred samples were stirred at specified intervals (zero, three, 12 and 21 hours).
- All samples were weighed at zero, three, six, 12, 15, 21 and 24 hours.
- Water loss was measured and the hourly drying rate (L/m²/h) was calculated for each of the periods: 0–3 hours; 3–6 hours; 12–15 hours; 21–24 hours.

It was challenging to create experimental conditions that reflect reality. In reality, litter in a meat chicken shed is not completely stirred but will have regular disturbance due to chicken activity. Tilling the litter is a single event, but the chickens actively engage with the litter, by dust-bathing and digging, causing an extended period of litter disturbance after tilling has finished. In our experiments, litter was stirred at three, six, 12 and 21 hours to produce the greatest likely increase in evaporation rates compared with undisturbed litter. Therefore, the **evaporation rates measured for the ‘stirred’ litter samples should be considered as the maximum, and more conservative (lower) evaporation rates should be used in models when estimating the effect of tilling on litter drying rate.**

Evaporation rates decreased during the experiment (Figure 54). This was expected due to drying of the litter surface and moisture content reduction in the whole litter sample, both of which makes water less available for evaporation. Stirred litter samples had consistently higher evaporation rates than the unstirred litter. The evaporation rate of the unstirred samples in the 12–15-hour and 21–24-hour periods were used as an estimate of ‘long-term, steady-state’ evaporation rate, and the magnitude of the evaporation rate of the stirred samples at each time point were compared to these steady-state values (Figure 55).

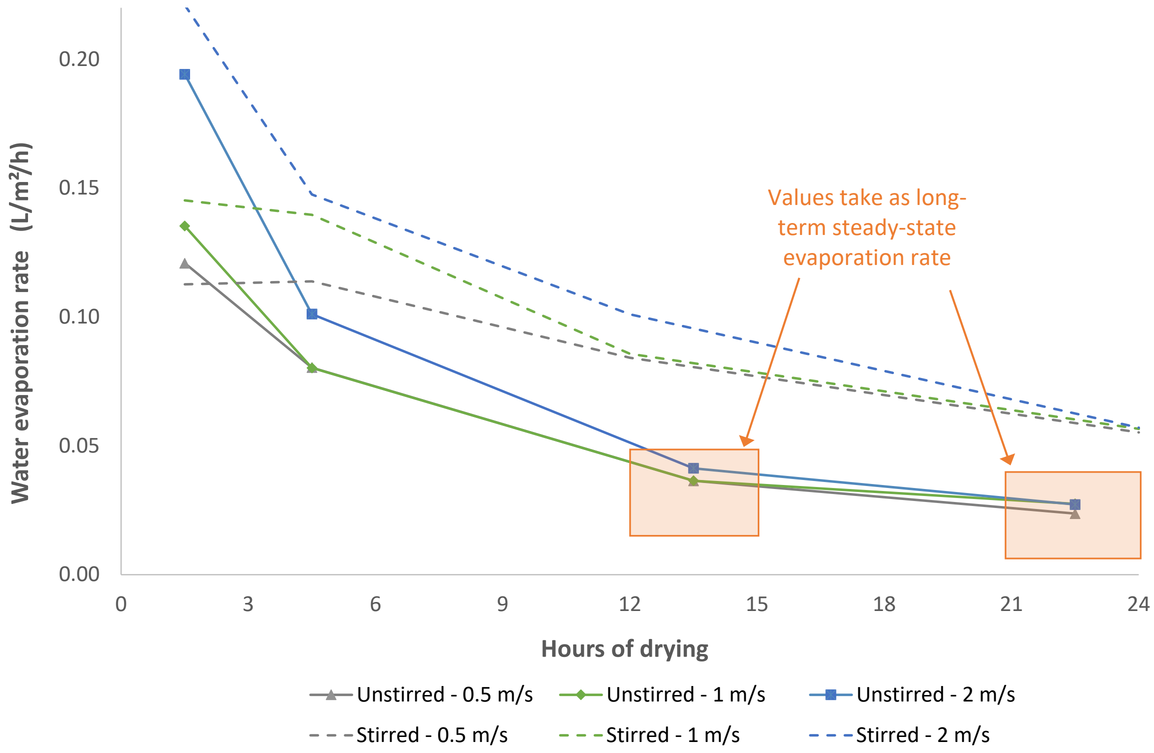


Figure 54. Example of evaporation rates measured during the experiment (litter was 47 days old and prepared to 30% moisture content, and the drying conditions were 25 °C and 50% relative humidity).

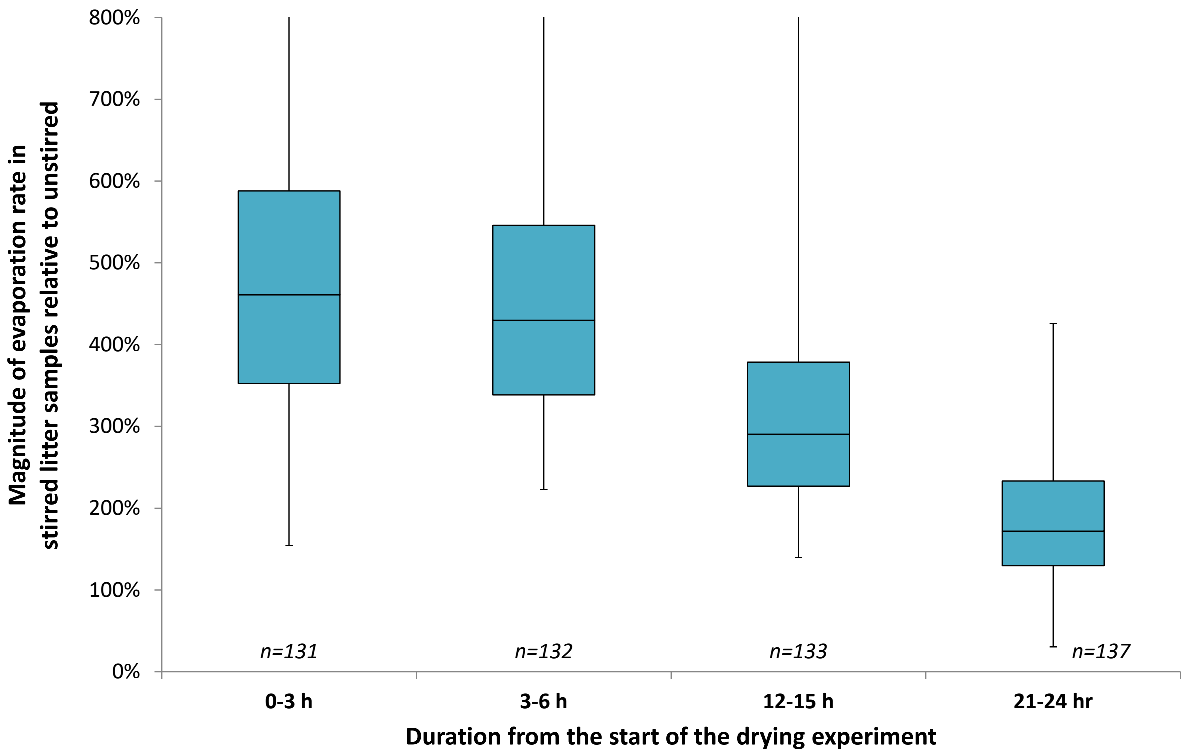


Figure 55. The magnitude of evaporation rate measured in the stirred litter samples relative to the long-term, steady-state evaporation rate of unstirred litter.

Boxes represent the 25th to 75th percentile; the line in the middle of the box is the median value (50th percentile); and the whiskers represent the maximum and minimum values.

Compared to untilled litter, we suggest that the evaporation rate from tilled litter would likely be:

- 4–5 times greater for up to six hours after tilling
- 2–3 times greater for 12–15 hours after tilling
- 1–2 times greater for 21–24 hours after tilling

Evaporation rate presumably returns to the pre-tilling value at some timepoint after 24 hours, although greater evaporation rates may be ongoing depending on the friability of the litter and the amount of chicken activity. **These increased evaporation rate values were accepted for use in modelling evaporation rate from litter following a litter tilling event.**

In previous experiments (unpublished data), the evaporation rate from caked litter was found to be about three times lower than friable litter. Applying this to the evaporation rates measured in this experiment, it follows that tilling caked litter would likely increase evaporation rates by:

- 12–15 times greater for up to six hours after tilling
- 6–9 times greater for 12–15 hours after tilling
- 3–6 times greater for 21–24 hours after tilling
- Three times greater than caked litter for as long as the litter remains friable.

Take home messages about the effect of tilling on evaporation rates

After tilling **friable** litter, evaporation rates are likely to be:

- 4-5 times greater for up to six hours
- 2-3 times greater for 12-15 hours
- 1-2 times greater for 20-24 hours.

After tilling **caked** litter, evaporation rates are likely to be:

- 12-15 times greater for up to six hours
- 6-9 times greater for 12-15 hours
- 3-6 times greater for 20-24 hours
- Three times greater for as long as the litter remains friable.

Airspeed at the litter surface during side-vent ventilation

Airspeed across litter surface is one of the critical contributing factors to evaporation, as evaporation rates increase proportionally with airspeed. Therefore, accurate modelling of evaporation requires accurate estimation of airspeed at the litter surface. In meat chicken sheds, there are two main modes of ventilation which create distinct airflow patterns.

Side-vent ventilation (Figure 56; also known as mini-vent ventilation or minimum ventilation) is designed to create very little air movement at the litter surface to prevent drafts. Air enters the shed through 80–150 small air vents that are installed along the full length of each side wall. Air enters though these vents under negative shed pressure and is projected towards the roof apex where it is warmed by heat trapped against the ceiling, before being pushed down towards the litter in the middle of the shed. Air circulates towards the side wall and repeats the cycle with new air entering the vent. Stale air continues to circulate and mix until it is exhausted out through ventilation fans.

Tunnel ventilation creates air movement along the length of the shed, reaching airspeeds of 1.5–3.5 m/s. In tunnel ventilation, air enters through large openings at one end of the shed and travels the full length of the shed (typically 110–180 m) before being exhausted through high-capacity ventilation fans. Airspeed can be estimated during tunnel ventilation by dividing the air flow through the fans (which can be estimated from fan test data and the shed's static pressure) by the aerodynamic cross-sectional area of the shed. This is because air currents are well-formed during tunnel ventilation and, on average, are assumed to be relatively even across the shed floor.

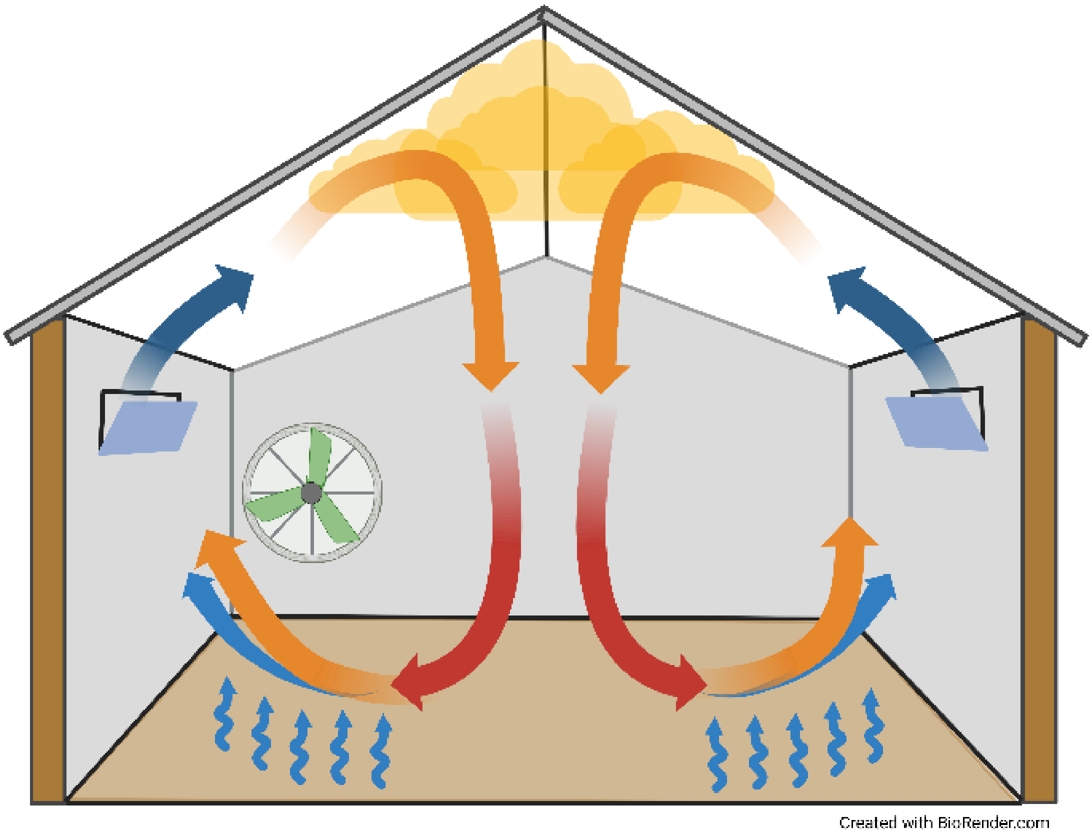

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Figure 56. Side-vent ventilation concept.

Side-vent ventilation is used most of the time (Dunlop and Duperouzel, 2014) whenever low to medium ventilation is required. The ventilation rate in the shed will increase with shed temperature, chicken age and density. Side ventilation transitions into tunnel ventilation during hot weather when higher airspeed is required to remove heat from the chickens and produce a windchill effect.

During side-vent ventilation, airspeed at the litter surface is designed to be minimal and is not well-defined. However, to accurately model evaporation of water from the litter surface, it is necessary to estimate the airspeed. No data was found in the literature regarding airspeed during side-vent ventilation in poultry sheds. Therefore, we attempted to measure airspeeds at the litter surface in commercial meat chicken sheds using airspeed sensors and data loggers (Figure 57).

Figure 57. Ultrasonic sensor and logger used to measure airspeed close to the litter surface during side-vent ventilation.

Airspeed measuring stations consisted of a 2D, ultrasonic airspeed sensor (Windsonic, Gill Instruments Ltd, Hampshire UK) and a temperature and relative humidity sensor (DOL 114 (dol-sensors A/S, Denmark) connected to a data logger (HOBO UX120-006M; Onset Computer Corporation, Bourne, MA, USA) and programmed to measure airspeed and direction every two seconds. The station was portable and battery powered. Two stations were installed in each shed, approximately halfway between the centreline of the shed and the wall where surface airspeed was expected to be horizontal and most well defined. Airspeed sensors were lowered towards the litter surface but kept above chicken head height to protect the sensor.

Surface airspeed measurement was undertaken in a single shed at two different farms for approximately the first 3–4 weeks of a grow-out. The intention was to measure the horizontal airspeed and correlate it to the ventilation rate while the shed was in side-vent mode. As the chickens grew, the airspeed sensor was raised to keep it away from them.

Airspeed data from the two sensors was analysed and scalar average airspeeds were calculated at two minutes intervals. This enabled comparison with the shed's ventilation data, which was recorded at two-minute intervals. As well as average airspeed, lower and upper values were also calculated using the 5th and 95th percentile airspeed value measured by the sensor each two-minute interval. Unfortunately, the ventilation computer failed in one of the sheds and the data was lost; however, surface airspeed data on its own was still considered valuable.

In the shed where ventilation data was available, airspeed close to the litter surface during side-vent ventilation (Figure 58) was found to be variable and not consistent with the ventilation rate (up to the maximum ventilation rate before the shed transitioned into tunnel ventilation). Using this data, a relationship was arbitrarily chosen so that recorded ventilation could be used to estimate airspeed at the litter surface:

Litter surface airspeed (m/s) = 0.6 x "side-vent %" + 0.2

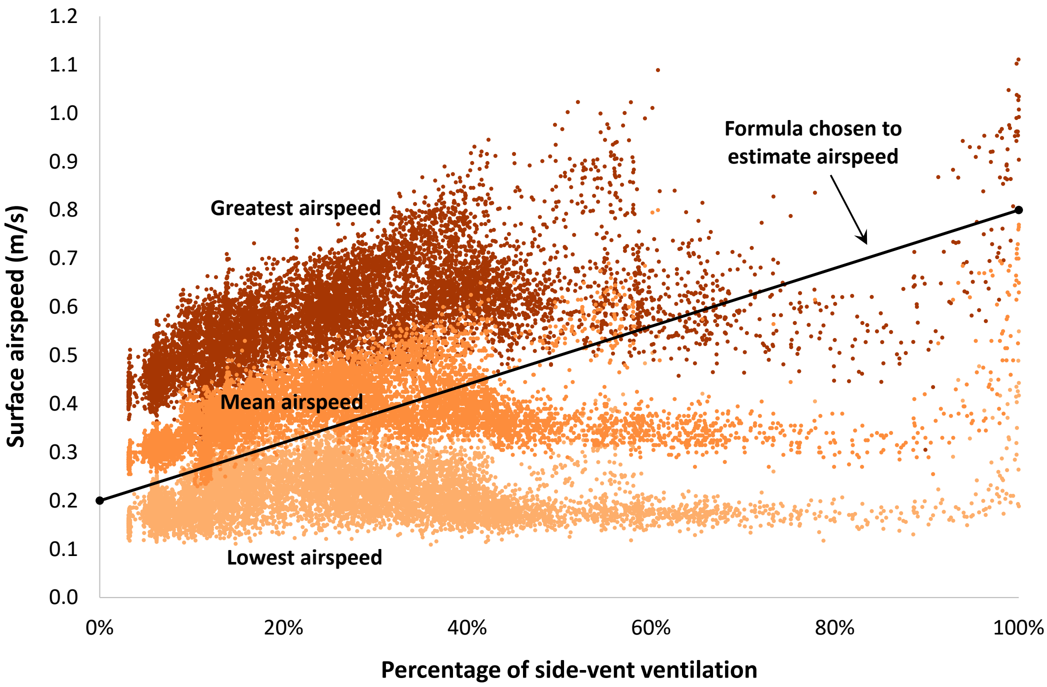


Figure 58. Comparison of airspeed measured close to the litter surface and the amount of side-vent ventilation (two-minute averaging periods).

At this same farm, time series records of the litter surface airspeed and percentage of side-vent ventilation showed a similar range of average surface airspeed, ranging from approximately 0.2 m/s to 0.8 m/s for most of the time that the shed was in side-vent mode (Figure 59). Being able to interpret this without ventilation data supports the use of the airspeed data that was collected in a separate shed, where the ventilation was not able to be downloaded (Figure 60). A similar range of litter surface airspeeds were measured at both farms (0.2–0.8 m/s), and so this was adopted for use in the litter drying model to predict the airspeed using shed ventilation rate.

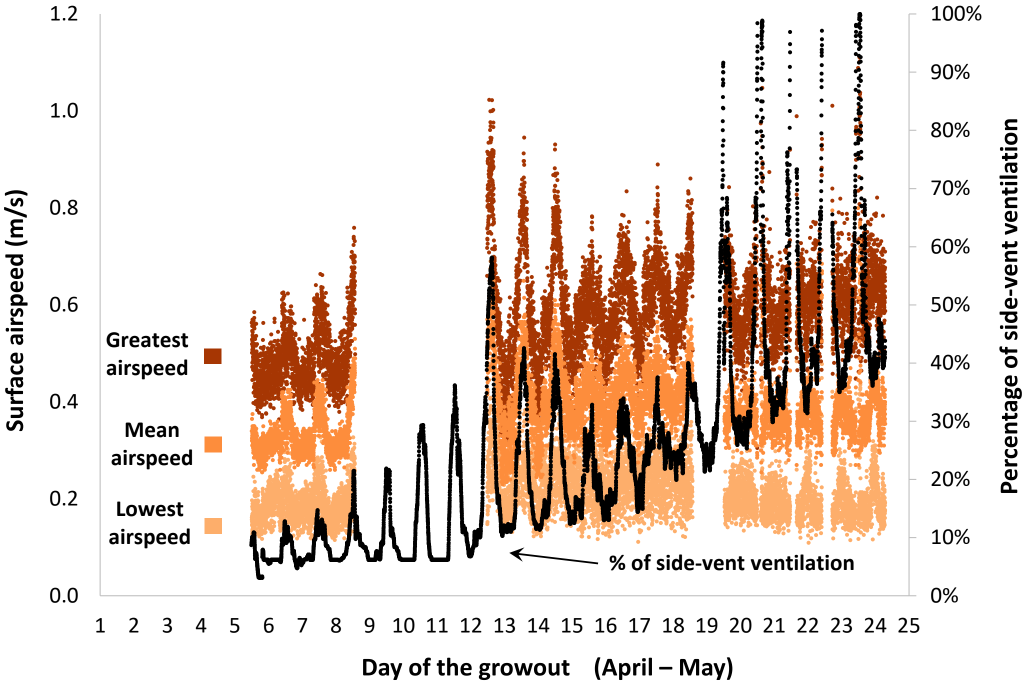


Figure 59. Litter surface airspeed and ventilation data while a meat chicken shed was in side-vent ventilation mode.

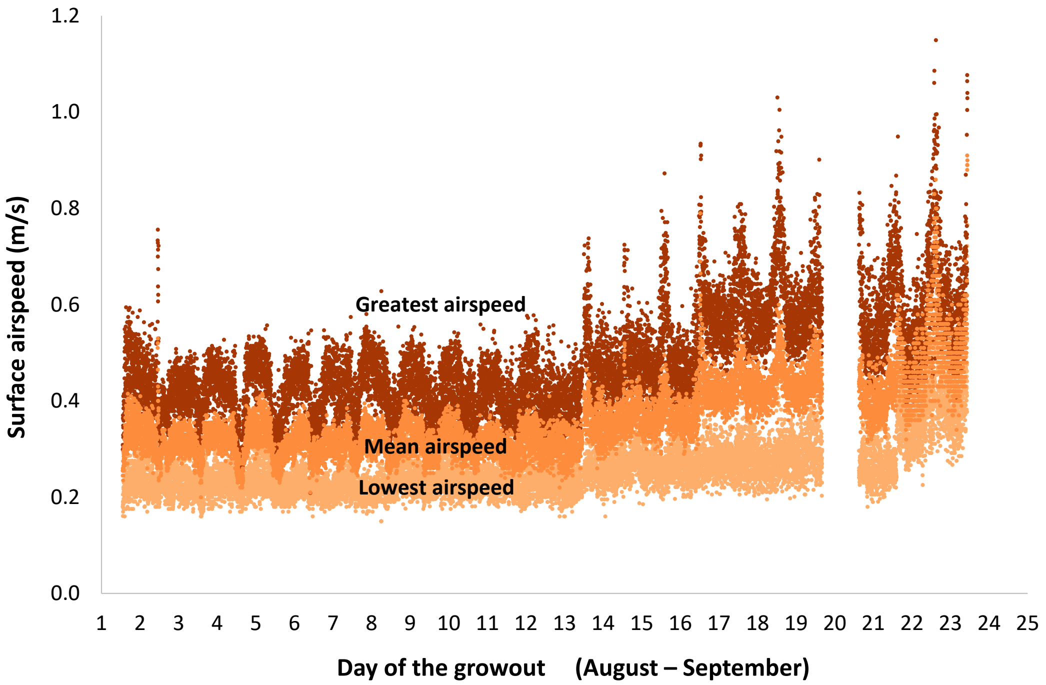


Figure 60. Litter surface airspeed during side-vent ventilation mode in a meat-chicken shed where ventilation data was unable to be downloaded.

Airspeed at the litter surface with a higher power circulation fan system

Higher-power circulation fan systems (HCFS) have been investigated previously due to potential chicken production and litter management benefits (Mou, 2020, 2021). Circulation or stirrer fans are not uncommon in Australian meat chicken sheds, but they tend to be low power (75–100 W) fans that only move air in their immediate area. By comparison, HCFS uses larger (~600 mm diameter) and more powerful (~150–500 W) fans that are arranged so that they work together as a system to get all the air moving in the shed in a controlled way (Figure 61). HCFS is designed to be run continuously so that the warm air that accumulates against the ceiling is brought down towards the floor. This warm air moves across the floor in a way that achieves uniform temperature and relative humidity throughout the shed, and an airspeed of approximately 0.8–1.0 m/s at the litter surface.

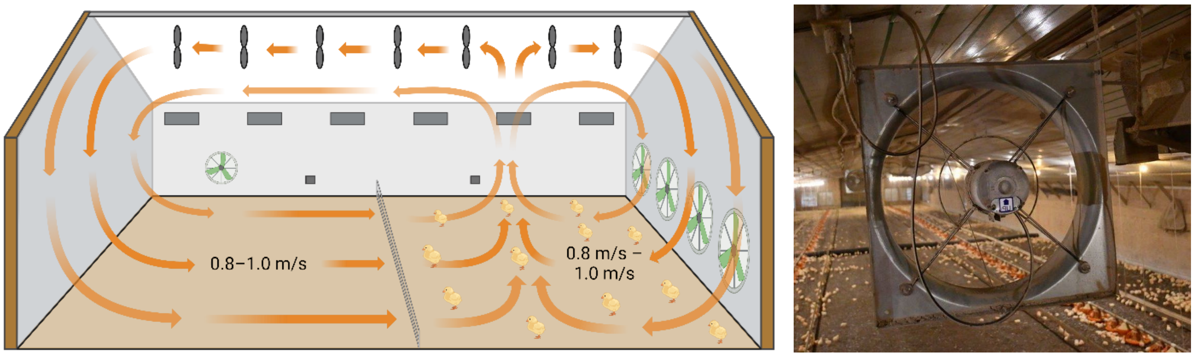


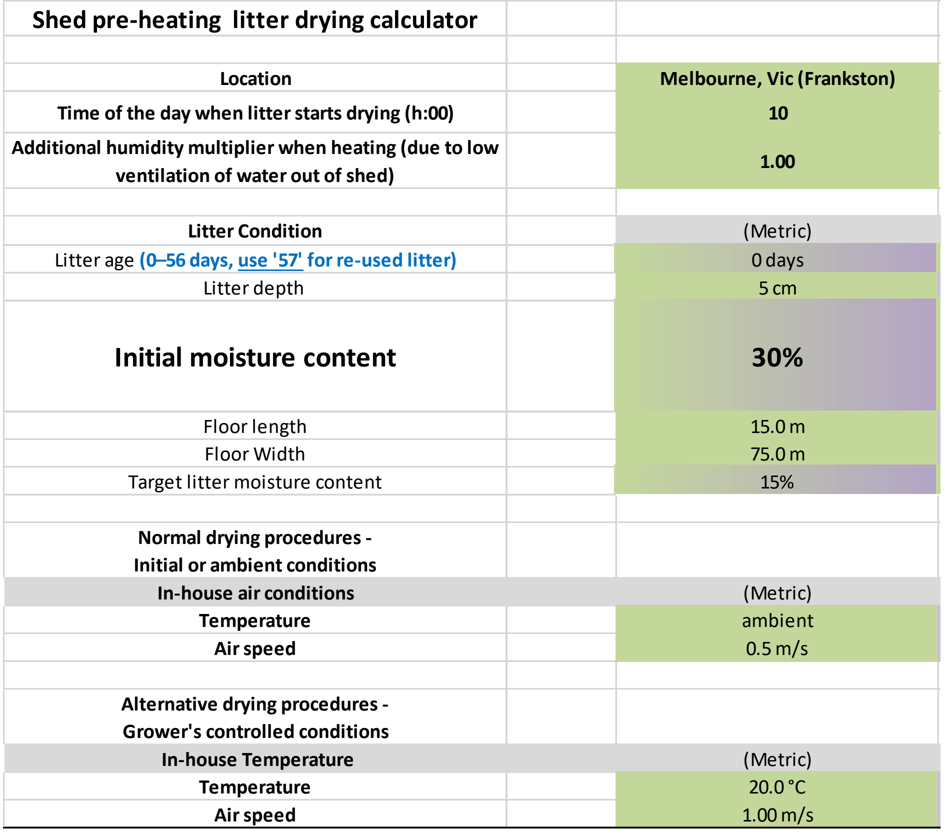
Figure 61. High-power circulation fan system (HCFS) (left) and example fan (right) used to create continuous airspeed of at least 0.8-1.0 m/s across the litter surface.

There are well-founded reasons why increasing air speed causes evaporation from litter to increase (Dunlop, 2021b). Previous on-farm trials of HCFS demonstrated significant benefits in terms of reducing the occurrence of wet litter, litter caking and footpad dermatitis (FPD) (Mou, 2020, 2021). Litter conditions were improved further when actions were taken to maintain relative humidity below 60%. As an input to litter moisture models, the addition of a HCFS was included as a potential management practice by having an option to set a minimum in-shed air speed, which was arbitrarily chosen to be 0.8 m/s.

Pre-placement litter drying model

A spreadsheet-based model was created to estimate litter drying before placement of day-old chick, especially for situations when wet bedding is delivered to a farm. The main purpose of this model was to investigate how litter drying times vary in response to different shed heating temperatures, air speeds and litter tilling frequencies. Weather observation data was obtained from The Bureau of Meteorology to give the model applicability in different meat chicken growing regions that have different climates.

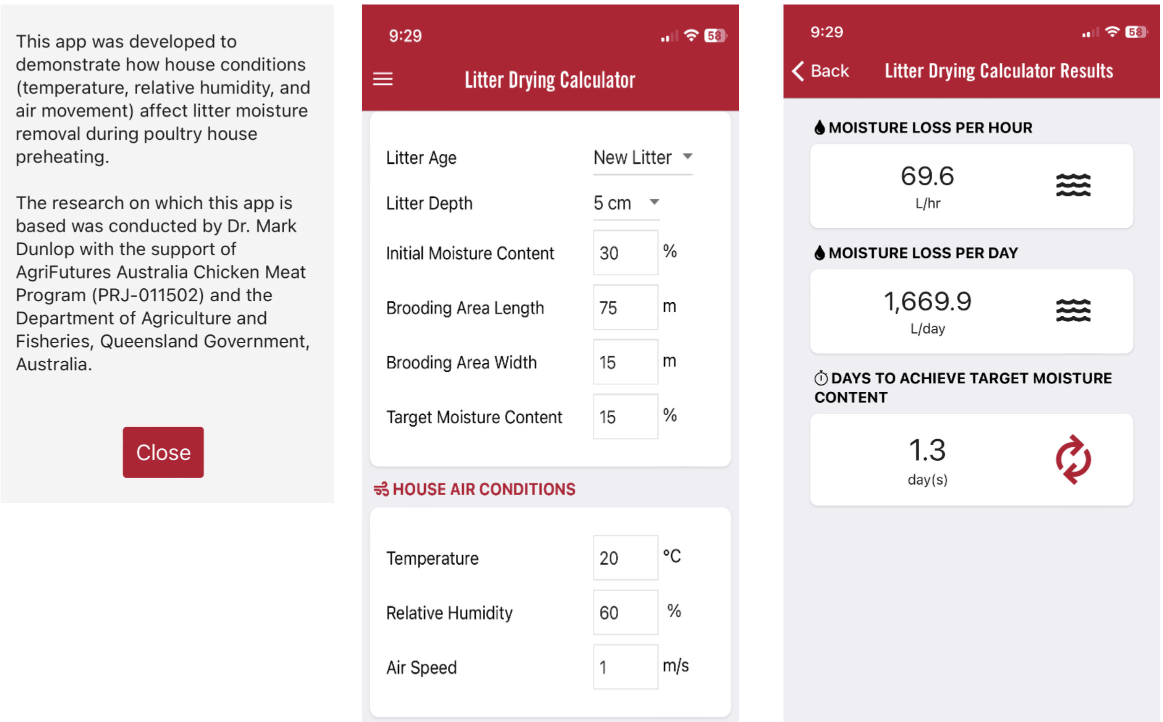
The *Shed pre-heating litter drying calculator* (Figure 62) used previously published formulas (Dunlop *et al.*, 2015) to calculate evaporation rates from litter and subsequent changes to moisture content over the course of each hour of the day. The spreadsheet in Figure 62 shows the input section for the model. The model enables the use of hourly weather observations (temperature and humidity), to simulate a case where a grower ventilates a shed without any extra heating. The model also allows the input of modified conditions, such as heating to a set temperature or increasing the air speed across the litter surface. These conditions can be controlled by the grower by changing heating settings and increasing the number of ventilation fans that are running. Some growers also till the litter to make it as dry as possible before the placement of day-old chicks. The increase in evaporation rate following tilling (described above in *Effect of litter tilling on evaporation rates*) was therefore added into the hourly time-step calculations. Results from the *Shed pre-heating litter drying calculator* have previously been presented (Czarick *et al.*, 2021; Dunlop, 2021a).



Shed pre-heating litter drying calculator		
Location		**Melbourne, Vic (Frankston)**
Time of the day when litter starts drying (h:00)		**10**
Additional humidity multiplier when heating (due to low ventilation of water out of shed)		**1.00**
Litter Condition		(Metric)
Litter age **(0–56 days, use '57' for re-used litter)**		0 days
Litter depth		5 cm
Initial moisture content		**30%**
Floor length		15.0 m
Floor Width		75.0 m
Target litter moisture content		15%
Normal drying procedures - Initial or ambient conditions		
In-house air conditions		(Metric)
Temperature		ambient
Air speed		0.5 m/s
Alternative drying procedures - Grower's controlled conditions		
In-house Temperature		(Metric)
Temperature		20.0 °C
Air speed		1.00 m/s

Figure 62. Shed pre-heating litter drying calculator input table with example inputs.

Calculations from this spreadsheet have also been programmed into a mobile app called *Litter drying time calculator* (Figure 63) by the University of Georgia, which can be freely downloaded from both the Apple store and Google Play.



This app was developed to demonstrate how house conditions (temperature, relative humidity, and air movement) affect litter moisture removal during poultry house preheating.

The research on which this app is based was conducted by Dr. Mark Dunlop with the support of AgriFutures Australia Chicken Meat Program (PRJ-011502) and the Department of Agriculture and Fisheries, Queensland Government, Australia.

Litter Age: New Litter
Litter Depth: 5 cm
Initial Moisture Content: 30 %
Brooding Area Length: 75 m
Brooding Area Width: 15 m
Target Moisture Content: 15 %

HOUSE AIR CONDITIONS

Temperature: 20 °C
Relative Humidity: 60 %
Air Speed: 1 m/s

MOISTURE LOSS PER HOUR: 69.6 L/hr

MOISTURE LOSS PER DAY: 1,669.9 L/day

DAYS TO ACHIEVE TARGET MOISTURE CONTENT: 1.3 day(s)

Figure 63. Screenshots of the *Litter drying time calculator* app by the University of Georgia.

Results from selected modelling scenarios

In the industry survey, growers reported that they use a variety of practices to dry bedding if it is delivered wet to the farm, included using ventilation fans, heaters, and tilling the litter (this is in addition to normal heating of the shed in preparation for the arrival of the chicks). The practices they choose depended on weather conditions, how wet the bedding is and how much time they have available to dry it to the required conditions. Growers said their greatest challenges occurred when bedding was delivered very wet, and they have limited time to dry it. Growers reported that drying bedding was much more difficult during cooler months and when there was high relative humidity.

We applied the model to investigate whether air speed, heat or tilling would contribute to the fastest drying. To simulate a ‘normal’ practice, we adopted a minimalist scenario:

- ‘Normal’ practice – minimalist approach
- Start with 30% moisture content bedding material
- Aiming to achieve a final moisture content 15%
- No heating (ambient temperature and relative humidity)
- 0.5 m/s airspeed (likely to be achieved by running a few ventilation fans in either tunnel or side-vent mode)
- No tilling/tilling the litter.

A variety of alternative procedures were modelled to investigate how long the drying time would be shortened by:

- Alternative practices
- Heating (to minimum in-shed temperatures of 15, 20 or 25 °C)
- Higher airspeed (1, 2 or 3 m/s)
- Litter tilling litter once (24 hours after spreading) or tilling the litter daily)
- Combinations of heat, higher airspeed and tilling.

Weather observation data used in the following examples was from the Mornington Peninsula, Victoria in late May. Daily temperatures were 5–19 °C and relative humidity was 40–90% (Figure 64).

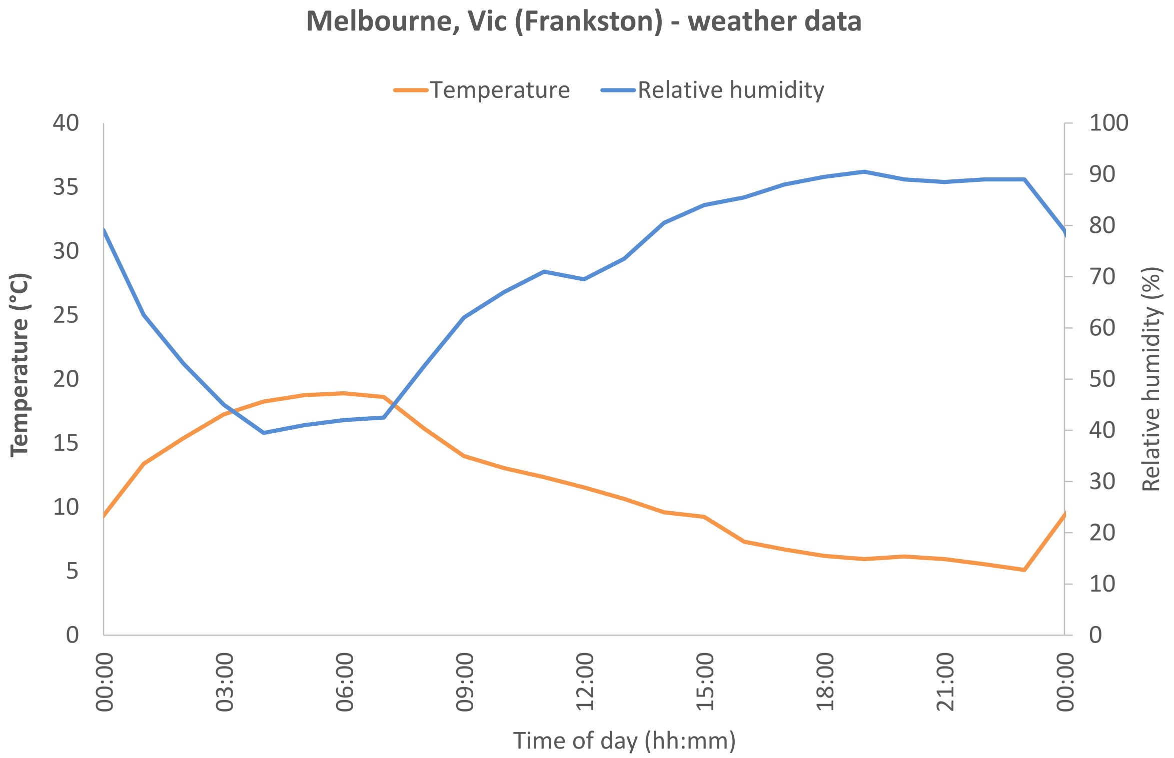


Figure 64. Hourly weather conditions used to demonstrate example outputs from the *Shed pre-heating litter drying calculator*.

According to the model, taking a minimalist approach resulted in very slow drying of the litter. After seven days, the moisture content was reduced to 21%, but was still far short of the arbitrary target of 15% (Figure 65). Increasing airspeed resulted in faster drying, but 2–3 m/s (approaching full tunnel ventilation in many sheds) would be required to get the bedding dry enough in four to six days, which is still likely to be longer than the time that growers have available.

When the shed is not being heated, evaporation rate slowed greatly between 10 pm and 10 am, as seen by flat sections in the drying curves in Figure 65.

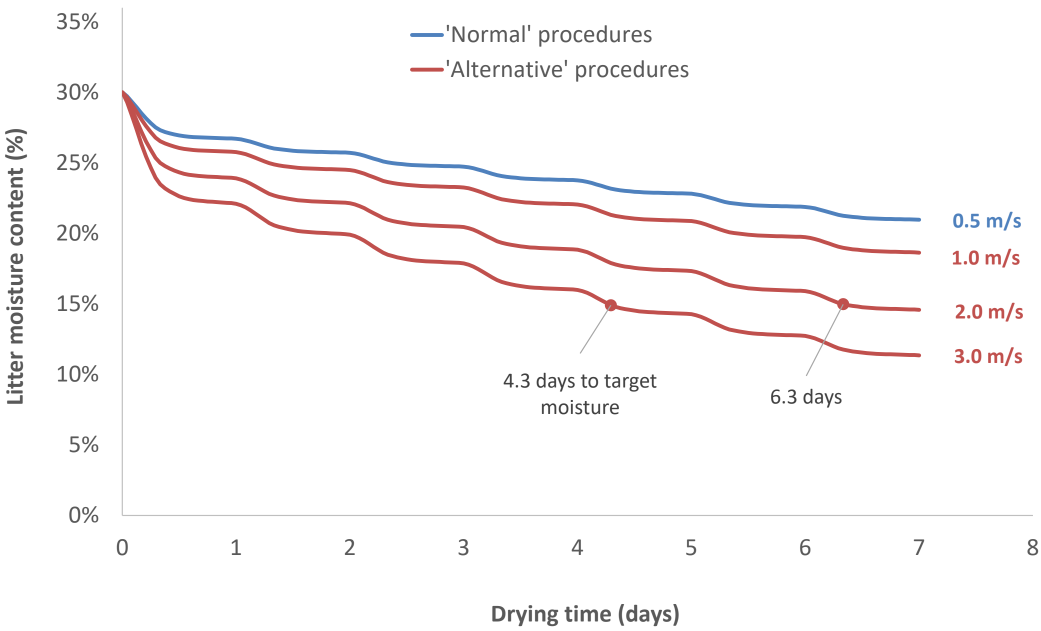


Figure 65. Example output from *Shed pre-heating litter drying calculator* showing the effect of increased airspeed on litter drying.

Heating the shed resulted in quicker litter drying (Figure 66). Increasing the temperature to a minimum of 15 °C to 20 °C had a similar effect as increasing the ventilation to achieve a minimum airspeed of 2.0 to 3.0 m/s. Further increasing the shed temperature to 30 °C shortened the drying time to just over two days to achieve the target moisture content (15%).

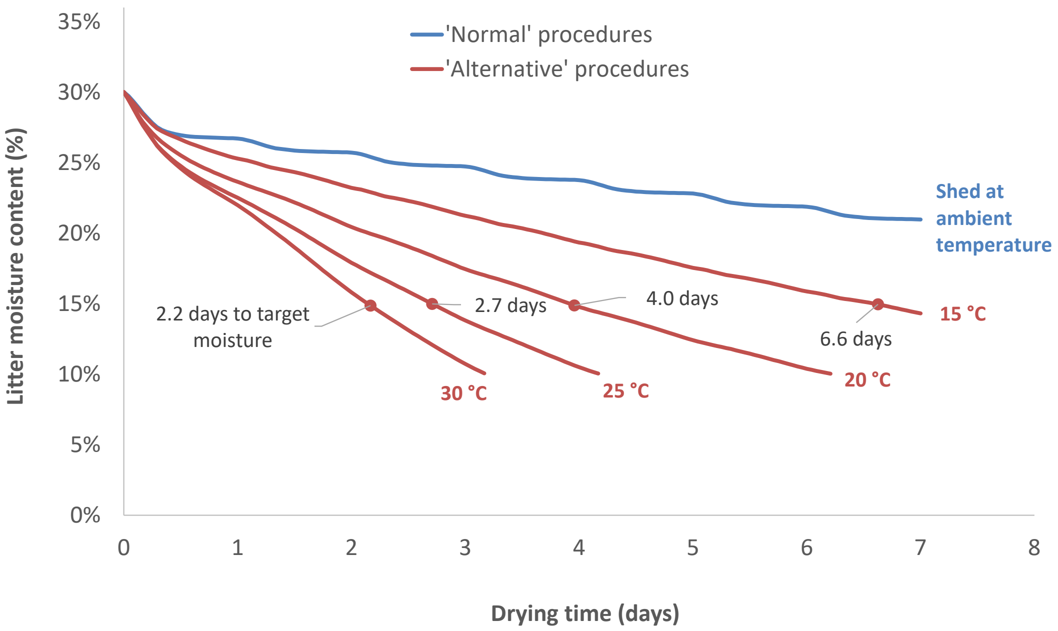


Figure 66. Example output from *Shed pre-heating litter drying calculator* showing the effect of heating on litter drying.

Tilling the litter increases litter drying for a short while immediately afterwards. In commercial chicken sheds, once the surface of the litter dries, water evaporation slows down substantially. In the *Shed pre-heating litter drying calculator*, tilling the litter just once reduced moisture content but then it had a similar drying rate to un-tilled litter (Figure 67). In comparison, daily tilling (at 10am) contributed to stepwise reductions in litter moisture content. But tilling alone still required five days to achieve the target moisture content (15%).

It is unlikely that a grower would invest time tilling the litter daily and not increase ventilation in the shed. By increasing the ventilation to achieve 2.0 m/s in the shed, the drying time was halved, and the target litter moisture content (15%) is reached in about 2.4 days. Low evaporation rate was also observed in this scenario between 10pm and 10am, and therefore growers might reduce the ventilation overnight to save power.

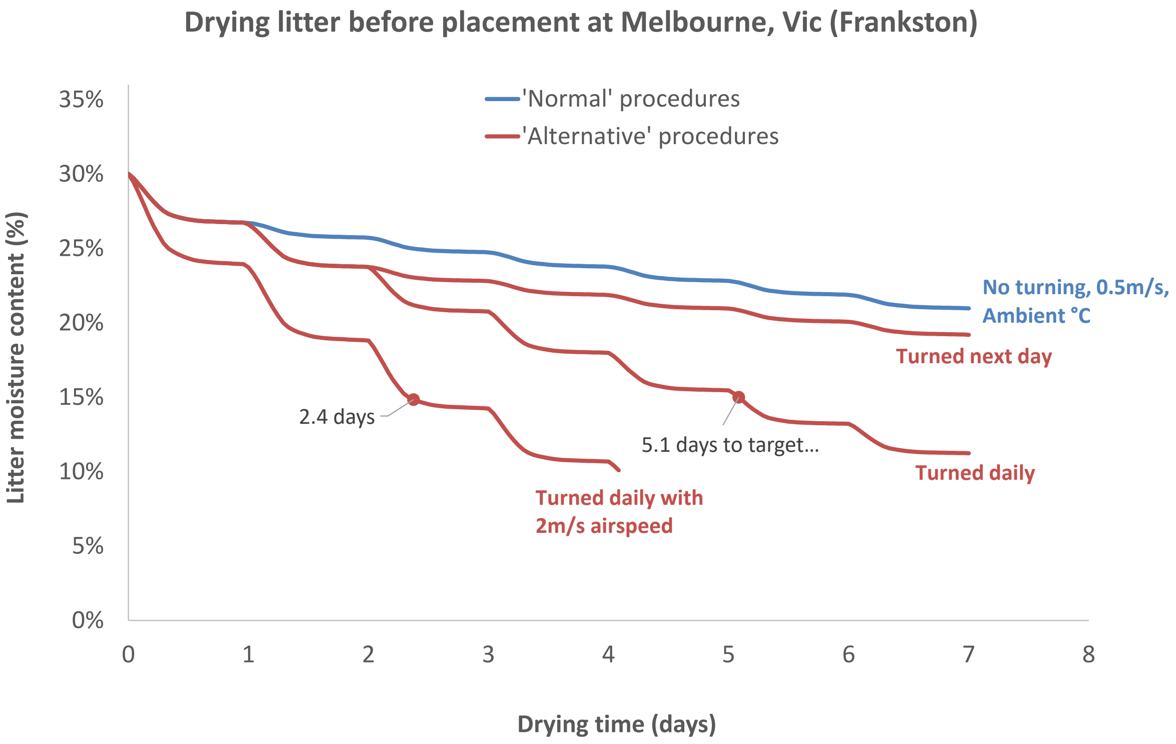


Figure 67. Example output from *Shed pre-heating litter drying calculator* showing the effect of litter tilling on litter drying.

A few scenarios were investigated combining heating, increased airspeed and tilling. Heating to 20 °C (Figure 68) and tilling the litter at least once shortened the drying time to 2.2 to three days. Increasing the airspeed to 1 m/s (as could be achieved with the higher power circulation fan system, introduced in the previous section) further shortened the time required to achieve the target litter moisture content to less than two days. Increasing the temperature to 25 °C shortened the drying time even further, with the target moisture content achieved in less than two days (Figure 69).

Outputs from the model demonstrated that dry litter is most effectively achieved with a combination of heat, airspeed and tilling. Growers can choose the practices that they would prefer to use depending on energy prices, labour availability, weather conditions, litter wetness and urgency.

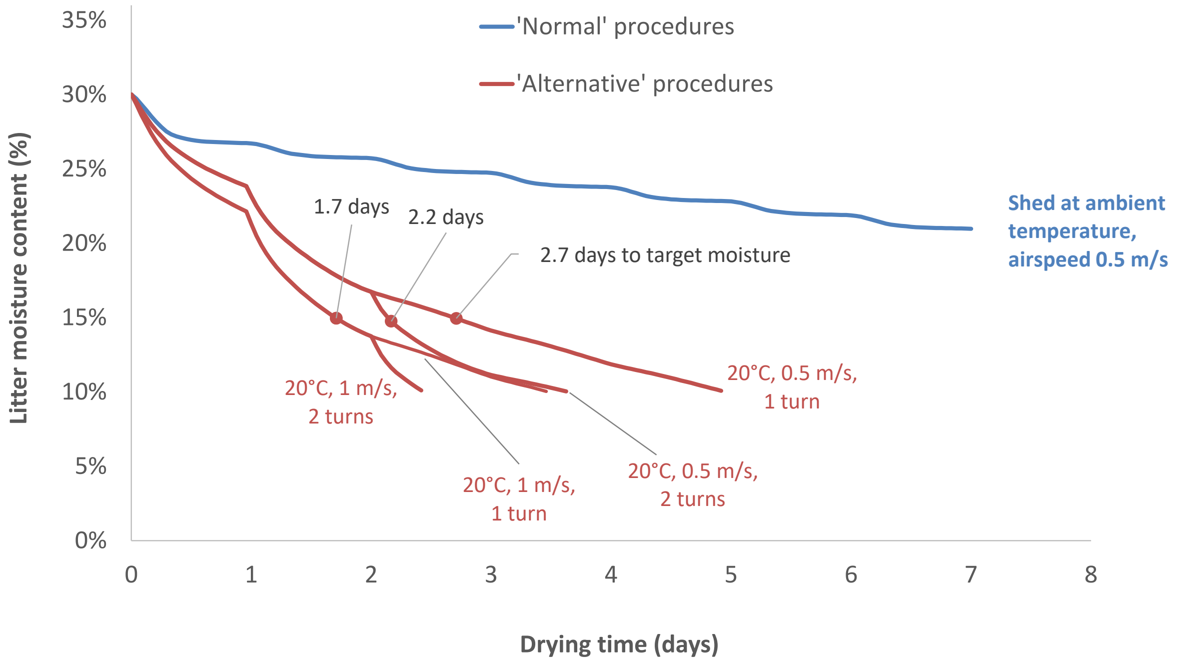


Figure 68. Example output from *Shed pre-heating litter drying calculator* showing the effect of heating to 20 °C combined with increased airspeed and tilling.

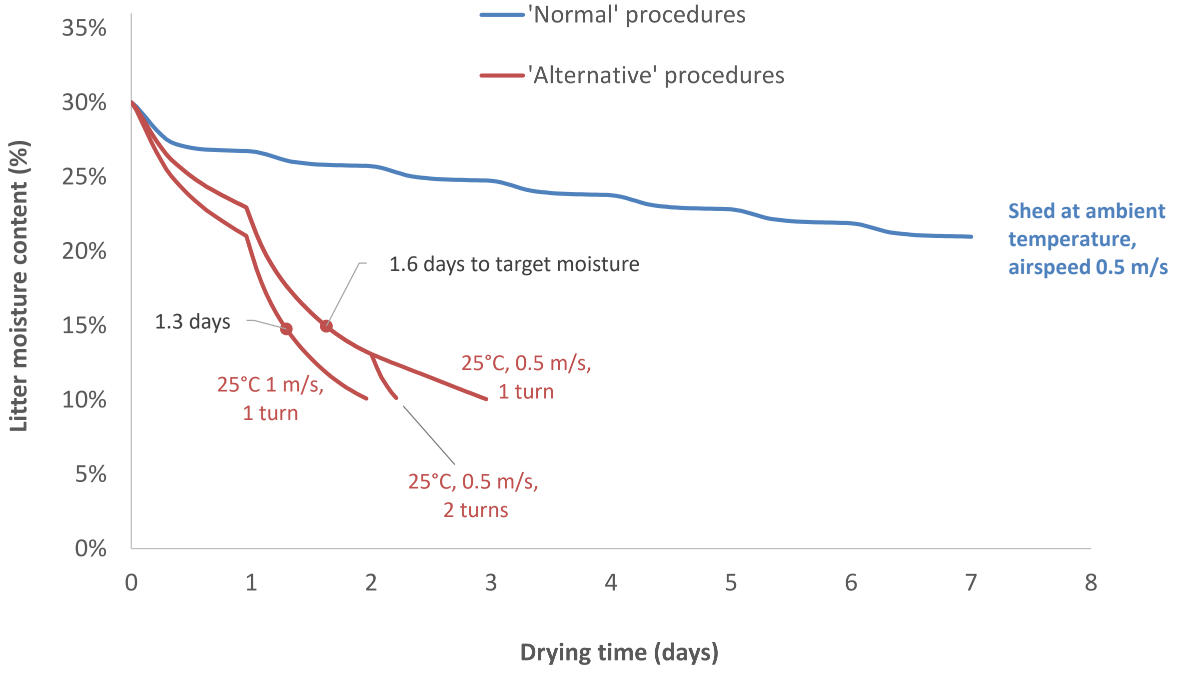


Figure 69. Example output from *Shed pre-heating litter drying calculator* showing the effect of heating to 25 °C combined with increased airspeed and tilling.

Practices to dry litter quickly and efficiently before playing day-old chicks

Evaporation requires heat, airspeed and moisture to be available at the litter surface.

Litter will dry more quickly if the shed is heated, if fans are tuned on to increase airspeed at the litter surface, and if litter is tilled to bring moisture to the surface.

Using a **combination of heat, airspeed and tilling** provides all of essential requirements for evaporation, even with only moderate values (20-25 °C, 1 m/s and tilling once or twice). In contrast, much higher temperatures (>30 °C), airspeed (~3 m/s) and frequent tilling would be required if used individually.

If not using heating, ventilation fans should be used from mid-morning until the evening. They may be turned off or reduced because evaporation is greatly reduced at night and early in the morning.

If using heating, growers should consider installing a system of circulation fans that can generate airspeed across the litter surface. Circulating air within the shed preserves heat rather than exhausting it straight out of the shed. Evaporating moisture from the litter increases relative humidity within the shed, and so it is still necessary to cycle exhaust fans to keep relative humidity down.

Litter moisture content simulation model

A computer-based model was developed to calculate changes in litter moisture content based on the formulas previously described by Dunlop *et al.* (2015). It utilised the water holding properties of litter and the estimated amounts of water added to and evaporated from litter. The model used real-world ventilation and production data from meat chicken sheds, including site-specific weather data. It was designed to estimate litter moisture content on an hourly basis and was able to predict the potential effects of alternative litter management strategies, such as:

- Tilling the litter more frequently
- Increasing minimum airspeed (potentially achieved using a system of air circulation fans)
- Reducing the maximum in-shed relative humidity (which can be influenced with heating, air exchange, cool-pad run-times and maintaining drier litter).

The model presented the litter moisture content using two different graphical presentations:

- Time series line graphs (Figure 70)
- Colour charts that used colours to represent the moisture content for every hour of the grow-out (Figure 71).

In the time series line graph, the duration of the grow-out was shown on the horizontal X-axis and litter moisture content on the vertical Y-axis. Tilling events were marked with a black ‘X’ and other data, such as the water added to the litter from droppings, could be displayed on the same graph.

In the colour chart, each cell represented an hour of the grow-out. The scale of litter moisture content was represented by a range of colours. Day-to-day changes in litter moisture content were presented going from left to right across the chart. Hourly changes during each day were presented going down the chart (morning at the top, midday in the centre, and midnight at the bottom). Tilling was represented by a black cell. The advantages of the colour chart included being able to present colour-coded hourly changes in litter moisture content more easily (colours ranged from cream or light blue for dry litter through to dark blue for wet litter).

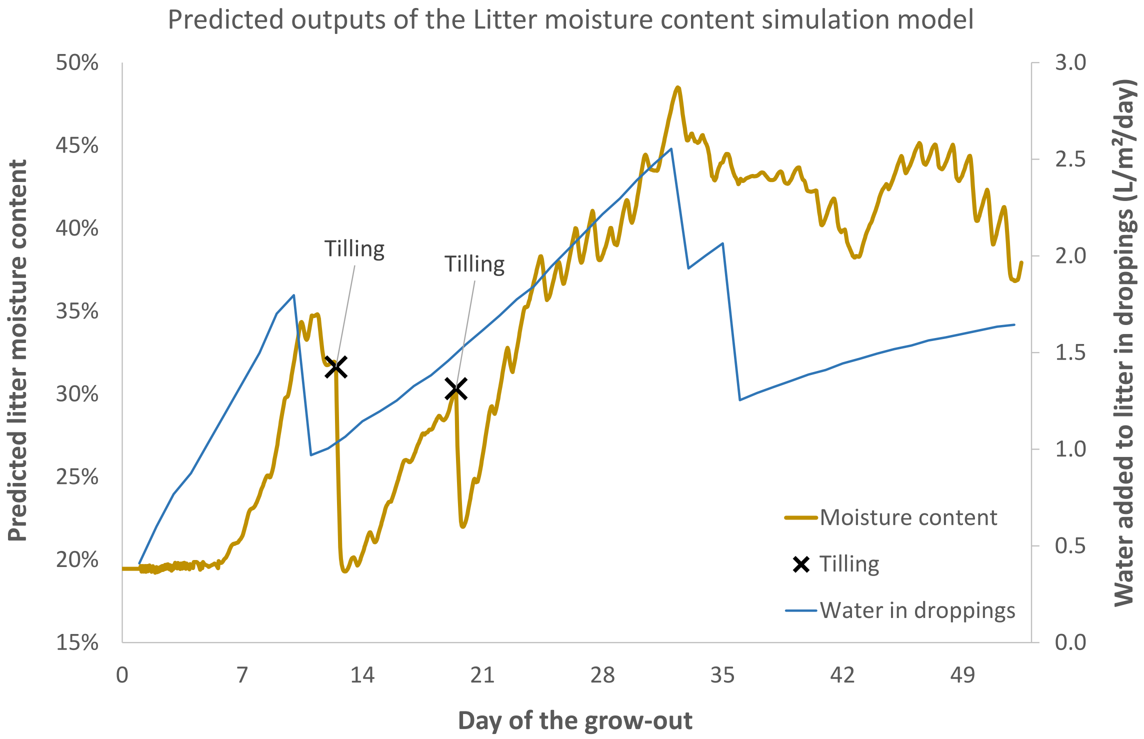


Figure 70. Example of the time series line-graph presentation of litter moisture content.

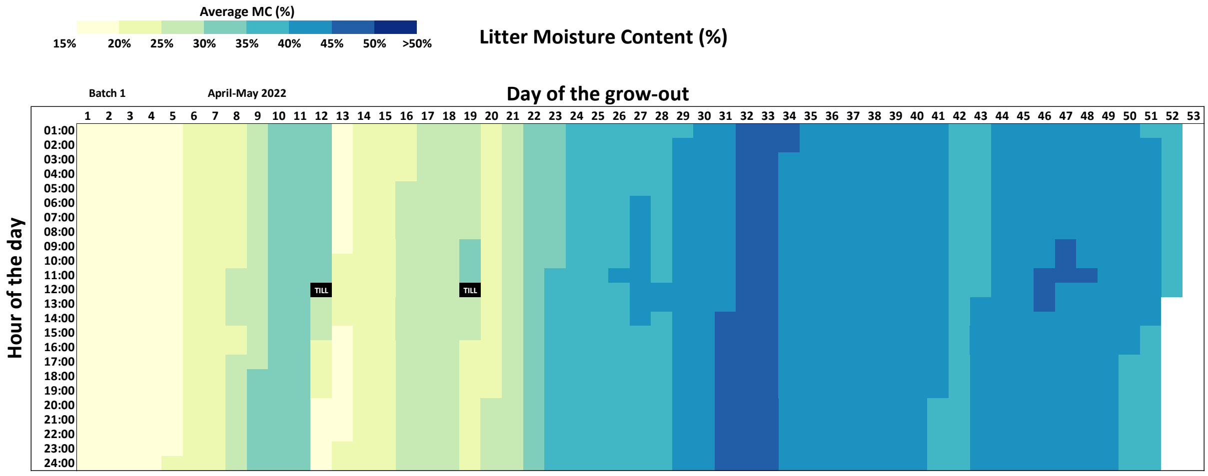


Figure 71. Example of the ‘colourmap’ representation of hourly changes in litter moisture.

The model was used to simulate the potential effects of alternative litter management on litter moisture content, including additional litter tilling, using higher-powered air circulation fans (minimum airspeed at the floor was increased to 0.8 m/s), and combining additional litter tilling and air circulation fans.

While the simulation model can apply changes to air speeds and evaporation rates due to tilling, the complete effect of these changes to management practice may not be evident due to the model’s reliance on shed temperature and relative humidity data that was measured in the shed when management practices weren’t modified.

We suggest that if a management practice reduces litter moisture content, then there is likely to be a reduction of the in-shed relative humidity and the litter is likely to be more friable and more heavily ‘worked’ by the chickens. These practices are likely to help keep the litter drier overall. Consequently, the simulated litter moisture content values calculated by the model should be regarded as an indicative change from the original (unmodified) scenario rather than an absolute estimate of actual litter moisture content in the shed.

Results of applying the litter moisture model at two commercial farms

The model was applied at two farms used during the ammonia measurement activities in this project (Farm A and Farm B) where ammonia and litter moisture content were measured on multiple occasions during the grow-outs. A single shed was used at each farm. Application of the model was limited to these two farms because it was not possible to obtain ventilation data from the others.

Both farms were located in South East Queensland and had sheds housing approximately 47,000 chickens, with nominal maximum ventilation rate of 550,000–570,000 m^3/h, provided by variable speed fans. Each farm tilled the litter at the end of brooding, and then at approximately weekly intervals until day 24–28 of the grow-out (but at Farm A, a mechanical failure in the tilling machine after day 19 resulted in no further tilling at this farm). At each farm, tilling was not performed after the thin-out because, based on the experience at both farms, litter friability improved with the reduction in stocking density and remained until the end of the grow-out. In general, the litter tilling frequency was consistent with information provided in the industry survey on litter management practices.

Comparison of modelled values to litter samples

Samples were collected for moisture content analysis before tilling, immediately after tilling and on the next day (approximately 24 h after tilling). The moisture content of the litter samples was compared with those predicted using the simulation model (Figure 72). The 'before tilling' time-point was used for assessing the predictions made by the model during normal conditions. The 'after tilling' and 'next day' time points were used for verifying the predictions to changes in moisture content due to increased evaporation rate in the 24 hours following tilling.

Statistical analysis was not performed as there were not enough data points or replication. The comparison between real and modelled evaluation is only qualitative. In general, moisture contents predicted by the model were within approximately five percentage points of the actual litter moisture contents (excluding the dry and wet grab-samples). On most occasions, the model predicted lower moisture content than was observed in the sheds. Moisture content predictions for the 'next day' were consistently lower than the collected litter samples, which indicated that the model may be over-estimating evaporation rate after tilling.

Given that this was the first attempt to model litter moisture content under commercial conditions, the model showed promising capabilities of simulating changes in litter moisture content in meat chicken sheds. To improve confidence in the modelling output, additional litter samples need to be collected and compared to modelled values.

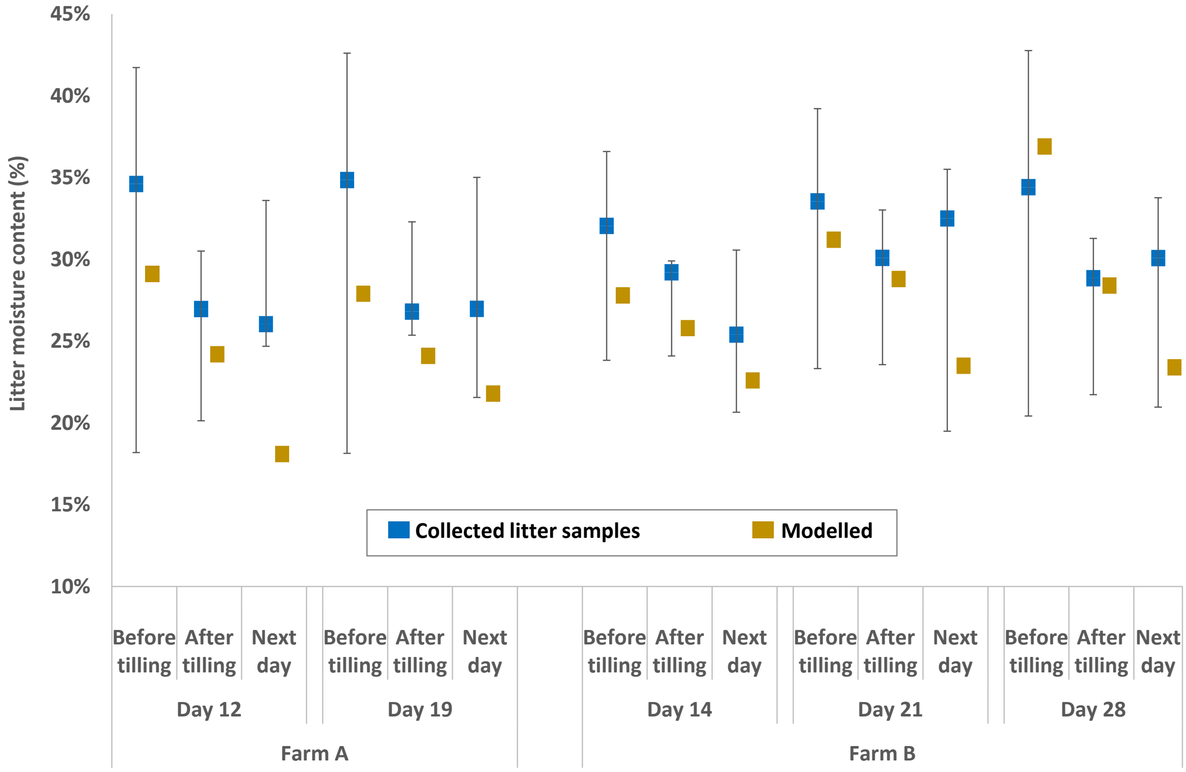
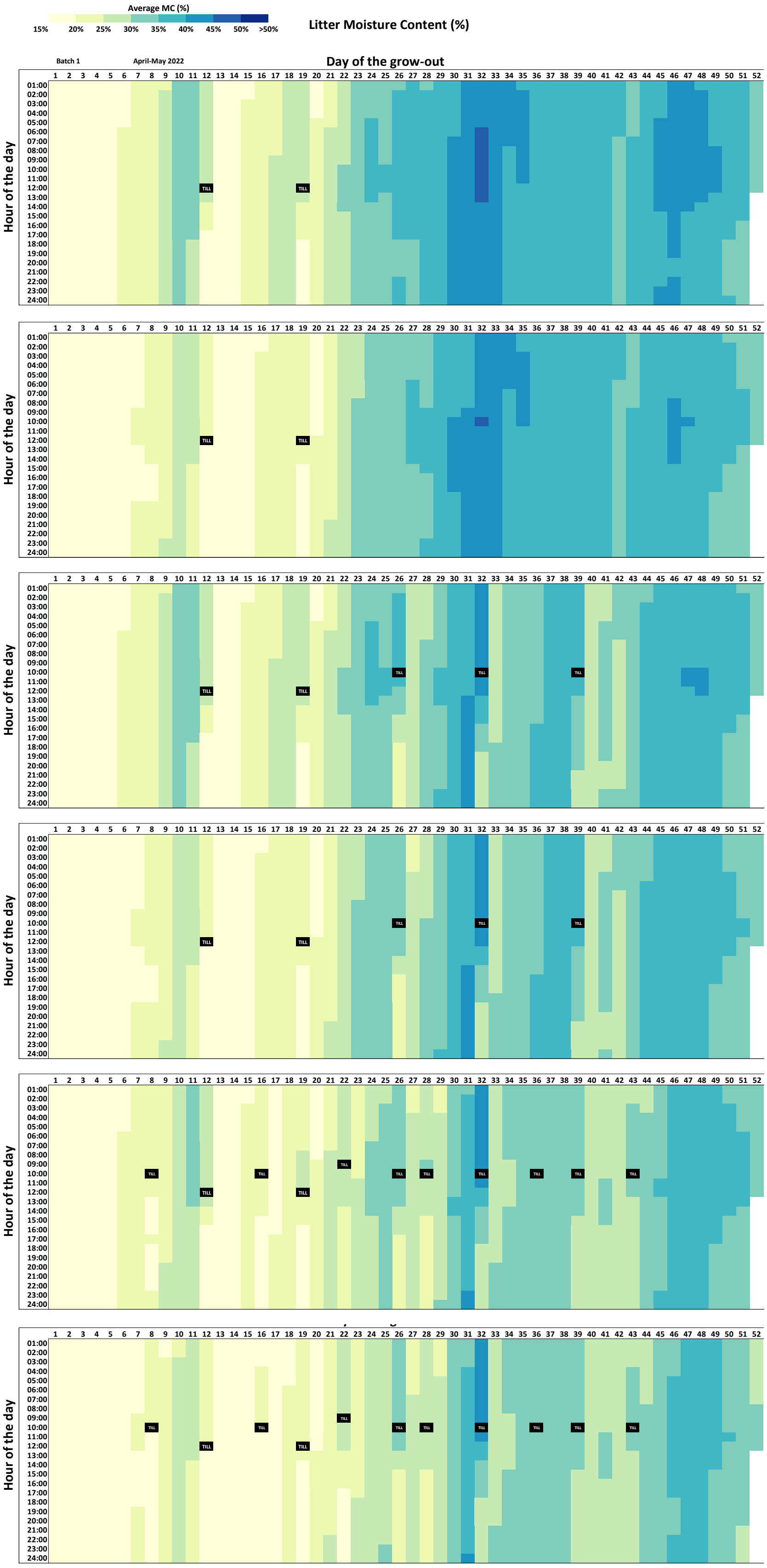


Figure 72. Litter moisture content values for collected litter samples compared to model-predicted values. For the collected samples, the blue square indicates the representative value for the whole shed (determined from multiple samples on designated transects). The whiskers represent the range of dry to wet litter in the shed from grab-samples of visibly dry or wet litter.

Model outputs and simulation of alternative management practices

Colourmaps of litter moisture content that were predicted using ‘as observed’ conditions or alternative litter management practices are presented in Figure 73 and Figure 74 for Farm A and Farm B, respectively. Line graphs of moisture content for both farms are provided in Appendix 5.

In an additional modelling exercise, a full year (April 2020 to March 2021) of shed ventilation and production data was obtained for Farm A and used to model the effect of different seasons on litter moisture content (technical issues at Farm B prevented data from being available). Colourmaps of litter moisture content for this period are presented in Figure 75.



Modelling based on collected data

Note: This farm normally tilled litter on day 26, but could not during this grow-out due to a mechanical failure.

Simulated: Circulation fans

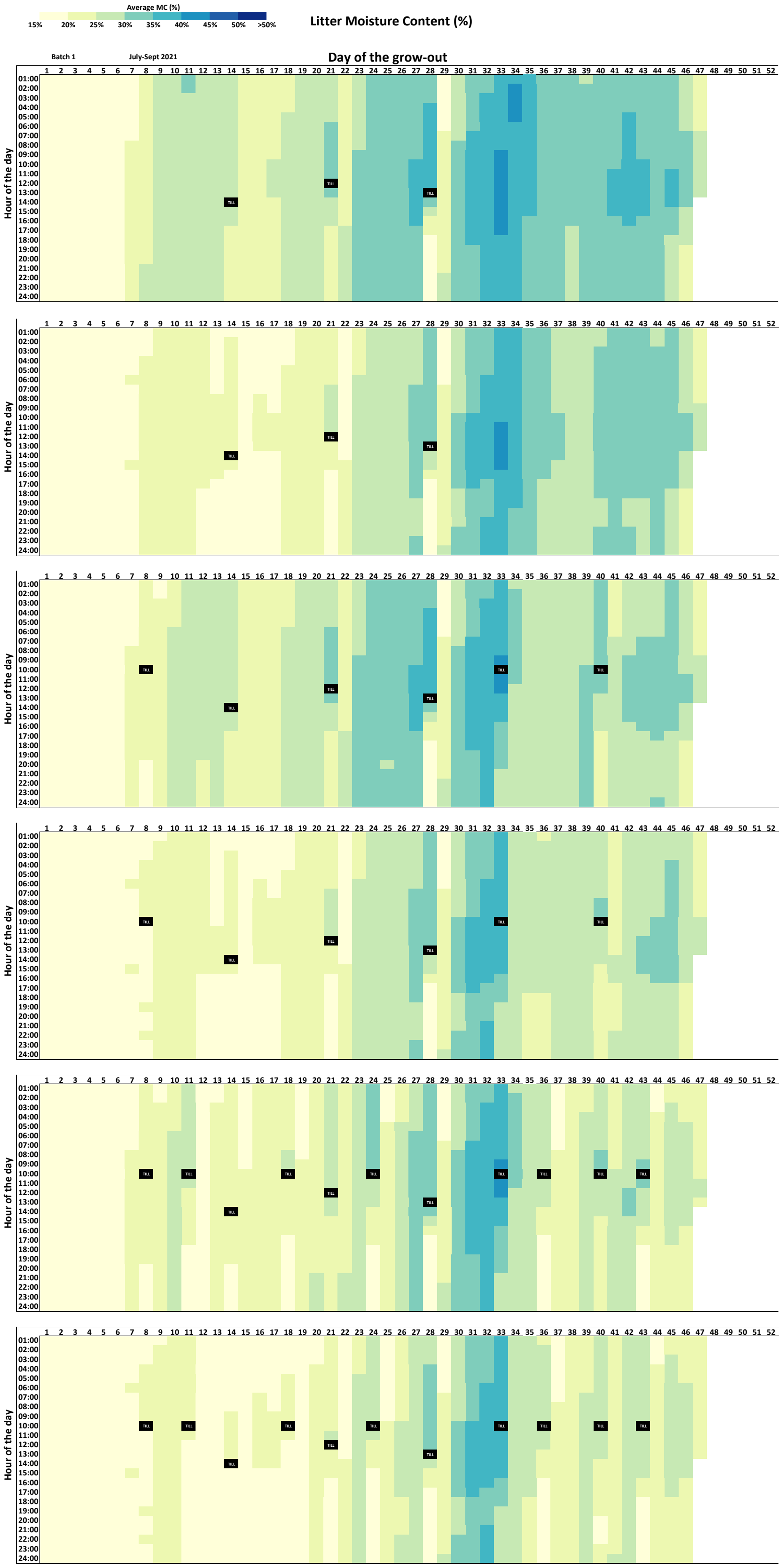
Simulated: Weekly tilling

Simulated: Weekly tilling plus circulation fans

Simulated: Twice weekly tilling

Simulated: Twice weekly tilling plus circulation fans

Figure 73. Farm A – colourmaps showing modelled hourly litter moisture content with alternative practices including additional litter tilling and/or use of a higher-powered circulation fan system.



Modelling based on collected data

Note: This farm normally tilled litter about day 26, but could not during this grow-out due to a mechanical failure.

Simulated: Circulation fans

Simulated: Weekly tilling

Simulated: Weekly tilling plus circulation fans

Simulated: Twice weekly tilling

Simulated: Twice weekly tilling plus circulation fans

Figure 74. Farm B – colourmaps showing modelled hourly litter moisture content with alternative practices including additional litter tilling and/or using a higher-powered circulation fan system.

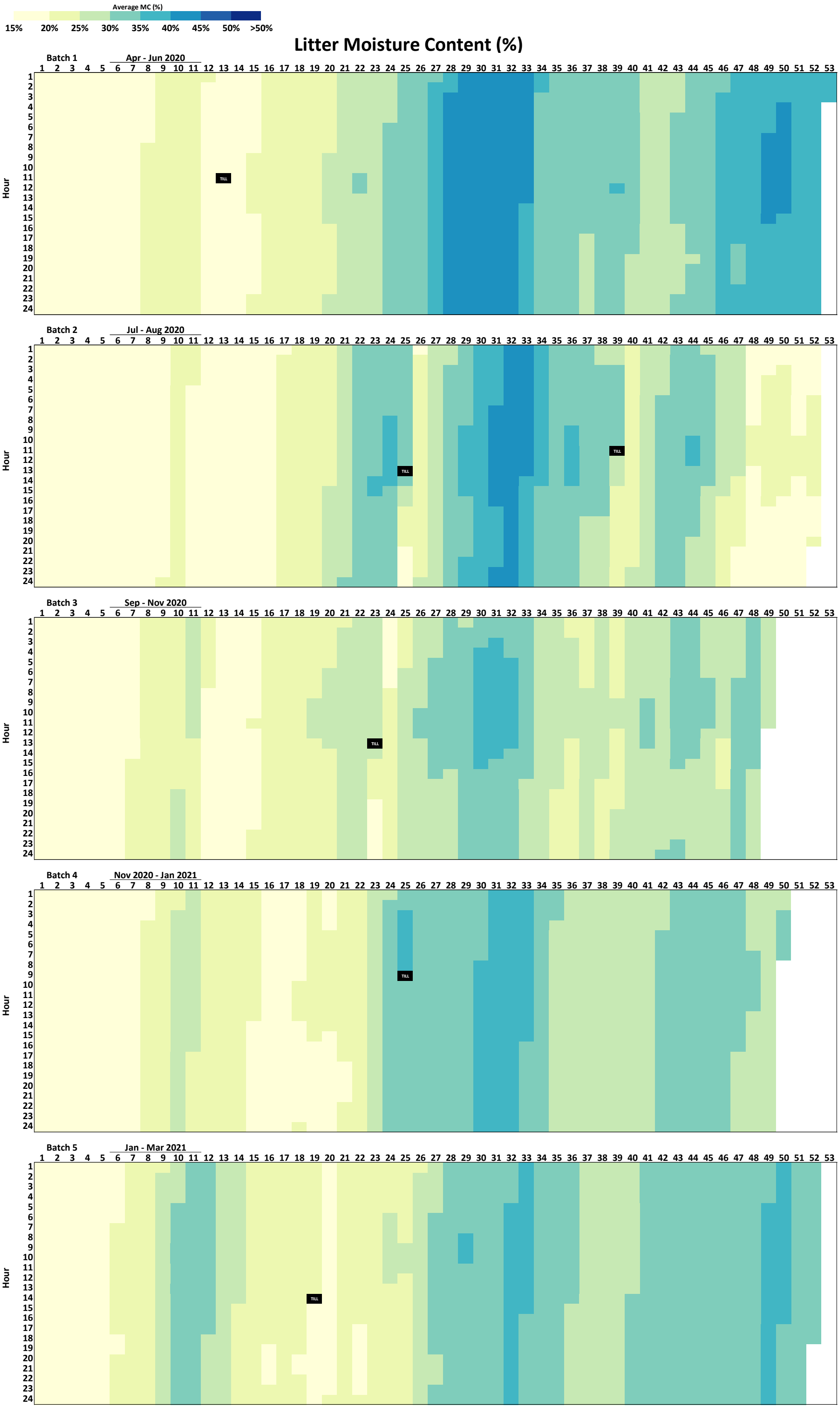


Figure 75. Farm A – colourmaps showing modelled hourly litter moisture content using five sequential batches (April 2020 to March 2021) of shed ventilation data.

Discussion about the litter moisture content simulation model

The *Litter moisture content simulation model* used real-world weather, ventilation and production data from meat chicken sheds, and combined it with empirical and theoretical calculations for moisture evaporation from litter. Using real-world data enabled normal daily and seasonal fluctuations to be modelled, but had limitations when simulating alternative practices, which were likely to change the in-shed temperature, relative humidity and airspeed conditions. The model was also limited to simulating 'average' conditions within the shed on an hourly time step and cannot be expected to model very dynamic or location-specific processes.

Consequently, the effects of complex processes such as air turbulence at the litter surface or differences in litter moisture content underneath drinker lines compared with other areas of the shed are unlikely to ever be included in the model. Nevertheless, this is the first model for poultry shed litter moisture, and further development, refinement and calibration will likely improve its accuracy and flexibility.

Compared to a limited number of litter samples, which were collected during litter tilling events at two farms, the modelled litter moisture content was within approximately five percentage points of the actual litter moisture content. The model tended to predict drier litter. The model also tended to over-predict drying following litter tilling and during some other occasions, such as brooding. Parameterisation of the model may need some adjustment to improve accuracy, but there is a need for many more litter samples to validate or adjust the calibration of the model.

Modelling multiple batches using data provided by chicken growers revealed the effect of different seasons on moisture content. We anticipate that climatic difference between growing regions will also be demonstrated if ventilation data is available from farms in different regions.

While not reported, the litter moisture content colourmaps were compared to other parameters and conditions including rates of drinking water consumption, relative humidity and evaporative cool-pad usage. These comparisons revealed that it was generally not just one factor that contributed to changes in litter moisture. Similarly, no single change to modelled management practices (for example, circulation fans or additional tilling) was able to completely alleviate predicted periods of wet litter. When applied appropriately, this *Litter moisture content simulation model* provided a preliminary tool for desktop assessment of alternative litter management strategies, and we suggest it could also be used to compare litter challenges and the effectiveness of management strategies in different growing regions.

Implications and recommendations for evaporation models

Addition and evaporation of moisture from litter in meat chicken shed represents a complex and dynamic water balance scenario with many contributing factors. Some factors are not readily able to be quantified or controlled. This makes on-farm research of litter management challenging, time-consuming and produces inconsistent findings.

Computer-based modelling provides an opportunity to control some of the conditions and allows the same scenario to be repeated multiple times while testing different treatments. The downside of computer-based modelling is that it may require over-simplification and reliance of experimentally derived estimations of very complex processes.

While developing the models, it became evident that there were some 'missing pieces' that needed to be understood to improve the validity of the models. We carried out some laboratory experiments and collected data to inform and guide the calculations used in the models. In doing so, we improved our understanding about the effects of tilling on evaporation rates as well as airspeeds close to the litter surface during side-vent ventilation.

The *Litter moisture content simulation model* is currently only suitable for research applications and requires input data from a shed's ventilation computer. Outputs are retrospective unless representative ventilation and weather conditions can be derived from historical grow-outs. Making the model more applicable will require representative regional weather data and a way to estimate in-shed conditions based on weather, production information and management practices.

We recommend that the models should continue being developed so they can be used as tools to investigate alternative management strategies and outcomes in different climatic regions. The *Litter moisture content simulation model* appeared to over-estimate evaporation processes, especially following litter tilling and during brooding. Additional validation of the models using litter samples from meat chicken sheds is recommended.

Implications and recommendations

This project has covered a broad range of topics relating to litter conditions, litter management practices, ammonia and odour. An industry survey captured a snapshot of how Australian meat chicken growers manage litter, with a focus on litter re-use and litter tilling. In the survey, growers expressed some concerns regarding litter tilling and litter re-use. Information from the survey provided direction and prioritisation of research activities in this project, and the development of fact sheets and other resources to assist growers with managing litter.

A comparison of litter moisture content to condition scores described in the *Litter guide – Daily litter condition assessment* has shown that this method allowed litter conditions and moisture to be quickly assessed on commercial farms or in research situations. We recommend that future research continue to use the assessment method. Research should also be considered to relate litter scores for litter moisture, friability and overall condition to quantify chicken health, welfare and production-related outcomes.

Measuring ammonia during and after litter tilling events showed that ammonia concentration can exceed the target value of 15 ppm. Growers already use additional ventilation to mitigate the 'spike', but our measurements suggest that increased ventilation is sometimes required. We recommend that growers maintain the increased ventilation for two to six hours after tilling finishes and be aware that some additional ventilation may even be required for twenty-four hours. The actual amount of extra ventilation cannot be prescribed as there are many influencing factors. We recommend that growers be made aware of post-tilling ventilation requirements.

Carbon dioxide concentrations did not increase due to litter tilling and therefore growers do not need to take any specific actions in terms of mitigating this gas, other than continuing to follow minimum ventilation recommendations.

Odour emissions rates (OER) were found to increase during tilling, pick-ups and litter clean-out activities. OERs increased by about 20% in comparison to untilled sheds but returned to normal levels within three hours. We recommend that growers take this into consideration when scheduling tilling or litter cleanout to ensure they undertake these activities at times when they are not likely to contribute to odour impacts.

Regarding tilling operations, there are potential research opportunities to increase the effectiveness of litter tilling machinery, and to investigate whether chicken behavioural research provides options for getting chickens to move more easily during tilling using ways that are aligned with their instinctive behaviours. Doing so may reduce the risk of injuries, fear and stress, and make tilling easier for operators.

Computational models to simulate litter moisture content and drying processes enabled desktop evaluations on a selection of litter management practices. One model has been applied in a mobile app by University of Georgia and is freely accessibly by Australian growers. We recommend that litter evaporation models continue to be developed to include more litter management strategies.

Growers will continue to strive to provide chickens with access to dry and friable litter. Fact sheets on topics relating to litter management practice were produced in this project, including cases studies of industry-tested solutions. The fact sheets will be hosted on a litter-focused webpage called *Litterpedia*, along with a troubleshooting guide to assist readers to find information relating to the issue or problem they are searching for. We recommend that AgriFutures Australia provides ongoing support with hosting *Litterpedia* and that the information, fact sheets and other resources be reviewed regularly and updated as necessary in consultation with industry.

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Appendices

Appendix 1 – Litter management survey

This survey is a part of a research project funded by the Australian chicken meat industry to measure odour, ammonia and carbon dioxide during litter tilling. Our research and your survey responses will be used to develop options for best practices relating to litter management. The aim of this survey is to find out and understand your current litter management practices and your experiences with litter re-use. It is expected that this survey will take 10 to 15 minutes. Please answer all questions and detail any additional information when required.

The information collected in this survey is covered by our privacy policy.

Privacy Collection Notice

The Queensland Department of Agriculture and Fisheries (ABN: 66 934 348 189) is seeking to collect information from you, including your:

- Farm and operational details
- Views relating general poultry farming operations
- Name and contact details (which is optional in this survey, and you can choose not to provide).

This information will assist DAF staff to carry out the AgriFutures supported research, development and extension project- Litter and Environment BMPs (PRJ-011502). The information you provide will be used to design sampling programs to further develop this research project. Survey results will also be aggregated and included in the final report for the project.

You will not be identified in any publications arising from this project. Your personal information, including address, geographical location or any information that can make your identity apparent, will not be disclosed to any other parties unless clearly and expressly authorised or required by law. Individual property data is not published or made public in any way. If you have any questions related to the project, please contact Mark Dunlop on mark.dunlop@daf.qld.gov.au. If you would like further privacy information visit: https://www.daf.qld.gov.au/siteinformation/privacy, or email privacy@daf.qld.gov.au.

We are conducting this survey using SurveyMonkey, which means the information collected will be transferred outside Australia and stored securely on SurveyMonkey's servers. By volunteering to complete this survey, you agree to this transfer. You can find out more about how SurveyMonkey handles your personal information by clicking Privacy and Cookie Policy.

Questions about farm location, farm size, poultry shed characteristics and bedding materials

1. Firstly, are you a …

○ Grower
○ Integrator representative (e.g. service person, vet)

2. What region is your farm/s located? (Please select one; if you have multiple farms and wish to respond for all, please contact us)

- ○ North Queensland
- ○ South East Queensland
- ○ NSW Central Coast (e.g. Hunter Valley, Mangrove Mountain, Goulburn)
- ○ Inland NSW (e.g. Griffith, Tamworth)
- ○ Southern coast of Victoria (e.g. Geelong, Mornington Peninsula)
- ○ Inland Victoria (e.g. Bendigo)
- ○ Western Australia
- ○ South Australia
- ○ Tasmania

3. What is the capacity of your farm?

- ○ < 20,000 chickens
- ○ 20,000 – 100,000
- ○ 100,000 – 250,000
- ○ 250,000 – 400,000
- ○ > 400,000 chickens

4. Is your farm … (Tick all that apply)

- ☐ Conventional
- ☐ Free range
- ☐ Organic

5. What types of ventilation/fans do you use? (Tick all that apply)

- ☐ Tunnel ventilation
- ☐ Cross ventilation
- ☐ Natural ventilation
- ☐ Roof extraction fans
- ☐ In-shed air circulation or destratification fans

6. What type of heaters do you use? (Tick all that apply)

☐ Hot air/forced air/space heaters
☐ Small brood heaters
☐ Tube/radiant heaters
☐ Underfloor heaters
☐ Hot water/radiator/fin tube heaters
☐ Electric heaters
☐ Other (please specify)

7. Which of the following building design elements best describe your shed? (Tick all that apply)

☐ Walls – insulated solid
☐ Walls – curtains
☐ Walls – concrete
☐ Mini vents – metal
☐ Mini vents – plastic
☐ Tunnel inlets – tilt panel
☐ Tunnel inlets – curtain
☐ Clean skin/smooth shed
☐ Ceiling baffles
☐ Exposed purlins
☐ Exposed wall posts
☐ Exposed roof trusses
☐ Floors – concrete
☐ Floors – compacted earth
☐ Other (please specify

The next series of questions are about how you manage your litter.

8. Currently, what bedding material do you use most often? (Tick more than one if you use a mixture)

☐ Softwood sawdust
☐ Hardwood sawdust
☐ Softwood shavings
☐ Hardwood shavings
☐ Rice hulls
☐ Straw
☐ Peanut shells
☐ Paper
☐ Other (please specify)

9. What alternative bedding materials do you use when required? (Tick all that apply)

☐ N/A
☐ Softwood sawdust
☐ Hardwood sawdust
☐ Softwood shavings
☐ Hardwood shavings
☐ Rice hulls
☐ Straw
☐ Peanut shells
☐ Paper
☐ Other (please specify)

10. How often do you need to use alternative bedding materials?

○ Most batches
○ A few batches a year
○ Only when required
○ Never
○ Other (please specify)

Questions about litter re-use

11. Would you consider reusing litter if your normal litter sources became difficult and/or as an alternative practice?

- ○ Yes
- ○ No

12. Have you re-used litter in the past?

- ○ Yes
- ○ No

13. Was it a full re-use, or partial re-use? (Tick both if applicable)

- ☐ Full re-use
- ☐ Partial re-use

14. How often do you re-use litter in your operation?

- ○ 1-2 flocks per year
- ○ 3-4 flocks per year
- ○ All flocks
- ○ Only as required

15. What factors determine if you will re-use litter or not? (Tick all that apply)

- ☐ Cost of new bedding
- ☐ Availability of new bedding
- ☐ Integrator or company policy
- ☐ Pathogen or disease management
- ☐ Turnaround time between grow-outs
- ☐ Your decision
- ☐ Other (please specify

16. What do you do to make sure reusing litter is successful? (Tick all that apply)

☐ De-caking or removing wet or heavily soiled litter
☐ Windrowing or heaping between batches
☐ Spreading and drying before placing chicks (if yes, please state how many days in the ‘other’ box)
☐ Extra pre-heating (if yes, please state how long before placing the chicks in the ‘other’ box)
☐ Using a brood curtain with ventilation away from the brood
☐ Extra ventilation during brooding
☐ Using ammonia sensors to monitor ammonia concentration in the brooder section
☐ Other

17. What benefits did you experience when reusing litter? (Tick all that apply)

☐ No benefits
☐ Better insulation and warmth
☐ More friable and absorbent
☐ Increased litter depth
☐ Reduced bedding cost
☐ Increased spent litter value
☐ Better results and higher performance index factor (PIF) score
☐ Lower mortality rates
☐ Better weight gain
☐ Other (please specify)

18. Did you experience any challenges or negative impacts when reusing litter? (Tick all that apply)

☐ No negative impacts or challenges were experienced
☐ Benefits were inconsistent
☐ Work health and safety issues
☐ Increased ammonia levels
☐ Pathogen or disease issues
☐ Increased dust
☐ Additional labour
☐ Worse results and lower PIF score
☐ Higher mortality rates
☐ Darkling beetle management
☐ My spent litter buyer/user prefers single-use litter
☐ Other (please specify)

19. What factors limit you from reusing litter? (Tick all that apply)

☐ Never considered it
☐ Not practical in my operation
☐ Lack of knowledge
☐ Don’t have the required machinery
☐ Integrator or company policy
☐ Turnaround time between grow-outs
☐ Requires more labour
☐ Need to train staff or contractors
☐ My spent litter buyer/user prefers single-use litter
☐ Other (please specify)

20. On a scale of 1 to 5, please state your level of concern about reusing litter in **your** situation.

	1 – Not concerned	2	3	4	5 – Extremely concerned	N/A
Build-up of Ammonia concentration – affecting bird health	○	○	○	○	○	○
Increased presence of food safety pathogens	○	○	○	○	○	○
Increase risk of disease such as coccidiosis or Mareks	○	○	○	○	○	○
Increased odour	○	○	○	○	○	○
Council regulation	○	○	○	○	○	○
Licensing constraints	○	○	○	○	○	○
Integrator requirements	○	○	○	○	○	○
Work health and safety issues	○	○	○	○	○	○
Turn-arounds are too short between grow-outs	○	○	○	○	○	○

21. Any additional comments on re-use?

22. Any additional comments on sourcing litter or setting-up?

Questions about litter turning

The following questions are about how you condition litter.

23. Do you use litter turning machinery to maintain dry and friable litter?

- ○ No, I keep litter dry and friable with other management practices
- ○ Yes, I use litter turning machinery
- ○ Other (please specify)

24. What is the type of machinery used?

- ○ Rotary hoe
- ○ Flail mower
- ○ Power harrows
- ○ Purpose-built (e.g. TUFFASS)
- ○ Other (please specify)

25. What is the size of your litter turning machine?

- ○ Walk-behind machine
- ○ Small tractor-driven (up to 1.8 metres wide)
- ○ Larger tractor-driven (wider than 1.8 metres)

26. What triggers a litter turning operation within your sheds?

- ○ Scheduled maintenance
- ○ In response to caking
- ○ Other (please specify)

27. Where does the caking occur?

- ○ Evenly throughout the shed
- ○ Under drink lines
- ○ Near migration fences
- ○ Other (please specify)

28. How much caking does there need to be before conditioning?

○ 5-10% of the whole floor
○ 10-25% of the whole floor
○ 25-50% of the whole floor
○ 50-75% of the whole floor
○ Other (please specify)

29. How often do you litter turn each shed?

○ Daily
○ Twice weekly
○ Weekly
○ Less often than once per week

30. What prevents you from conditioning your litter? (Tick all that apply)

☐ Bird age
☐ Bird density
☐ Raising drinker and feed lines
☐ Skilled labour shortage
☐ Equipment availability and suitability
☐ Concerns for bird welfare
☐ Insufficient time
☐ Other (please specify)

31. At what age are you **unable** to litter turn? (Tick all that apply)

☐ I can litter turn on any day
☐ Day 1-4
☐ Day 4-7
☐ Day 7-10
☐ Day 10-14
☐ Day 17-20
☐ Day 20-24
☐ Day 24-27
☐ Day 30-34
☐ Day 34-37
☐ Day 37-41
☐ Day 41-44
☐ Day 44-48
☐ Day 48-51
☐ Day 51-55
☐ Day 55-58

32. What areas of the shed do you litter turn? (Tick all that apply)

☐ Under drinkers
☐ Near migration fences
☐ Caked areas only
☐ Whole shed floor
☐ Other strategies (please specify)

33. What time of the day do you litter turn? (Tick all that apply)

☐ Early morning
☐ Mid-morning
☐ Noon
☐ Mid-afternoon
☐ Late afternoon
☐ Night-time

34. How long does it take to condition each shed?

○ Less than 30 minutes
○ 30 minutes to 1 hour
○ 1 to 2 hours
○ Greater than two hours

35. What other management practices do you use to maintain dry and friable litter? (Please detail)

36. Any additional comments about keeping the litter friable?

Option to provide contact details

37. Optional: Please provide your name and contact details

First name	
Surname	
Best contact number	
Preferred email address	

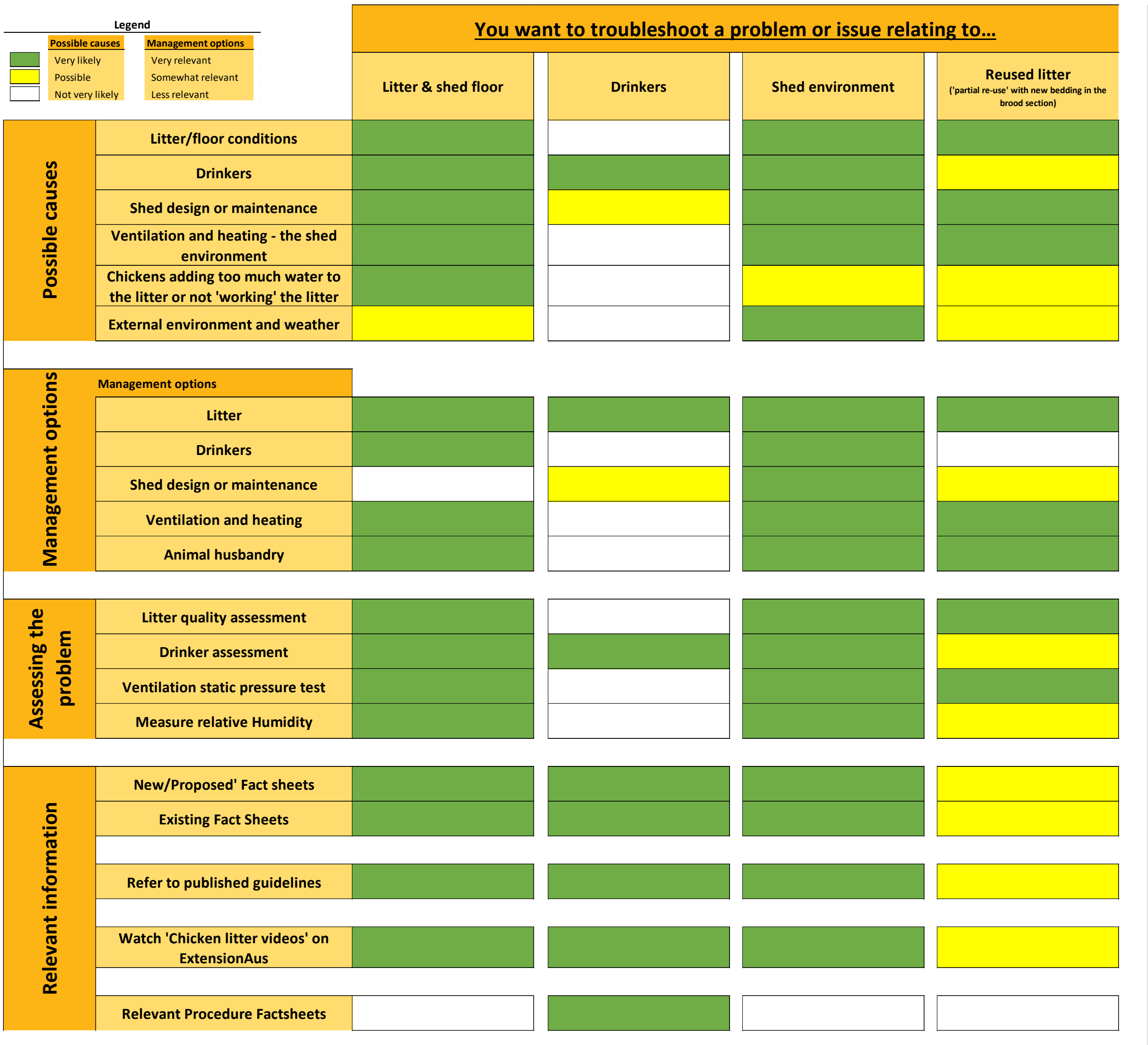
Thank you for your time in completing this survey, your contribution is greatly appreciated.

If you would like to share your litter management practices in more detail, please contact:

- Mark Dunlop - Mob: 0409 583 005 Email: mark.dunlop@daf.qld.gov.au
- Claire-Marie Pepper - Mob: 0472 834 413 Email: cm.pepper@daf.qld.gov.au

Appendix 2 – Litterpedia troubleshooting guide

Each of these category headings expands into multiple problems, possible causes, management options and resources.



Legend

	Possible causes	Management options
🟩	Very likely	Very relevant
🟨	Possible	Somewhat relevant
⬜	Not very likely	Less relevant

		You want to troubleshoot a problem or issue relating to…			
		Litter & shed floor	Drinkers	Shed environment	Reused litter ('partial re-use' with new bedding in the brood section)
Possible causes	Litter/floor conditions	🟩	⬜	🟩	🟩
	Drinkers	🟩	🟩	🟩	🟨
	Shed design or maintenance	🟩	🟨	🟩	🟩
	Ventilation and heating - the shed environment	🟩	⬜	🟩	🟩
	Chickens adding too much water to the litter or not 'working' the litter	🟩	⬜	🟨	🟨
	External environment and weather	🟨	⬜	🟩	🟨
Management options	Management options				
	Litter	🟩	🟩	🟩	🟩
	Drinkers	🟩	⬜	🟩	⬜
	Shed design or maintenance	⬜	🟨	🟩	🟨
	Ventilation and heating	🟩	⬜	🟩	🟩
	Animal husbandry	🟩	⬜	🟩	🟩
Assessing the problem	Litter quality assessment	🟩	⬜	🟩	🟩
	Drinker assessment	🟩	🟩	🟩	🟨
	Ventilation static pressure test	🟩	⬜	🟩	🟩
	Measure relative Humidity	🟩	⬜	🟩	🟨
Relevant information	New/Proposed' Fact sheets	🟩	🟩	🟩	🟨
	Existing Fact Sheets	🟩	🟩	🟩	🟨
	Refer to published guidelines	🟩	🟩	🟩	🟨
	Watch 'Chicken litter videos' on ExtensionAus	🟩	🟩	🟩	🟨
	Relevant Procedure Factsheets	⬜	🟩	⬜	⬜

Appendix 3 – In-shed ammonia concentration data

Farm A1

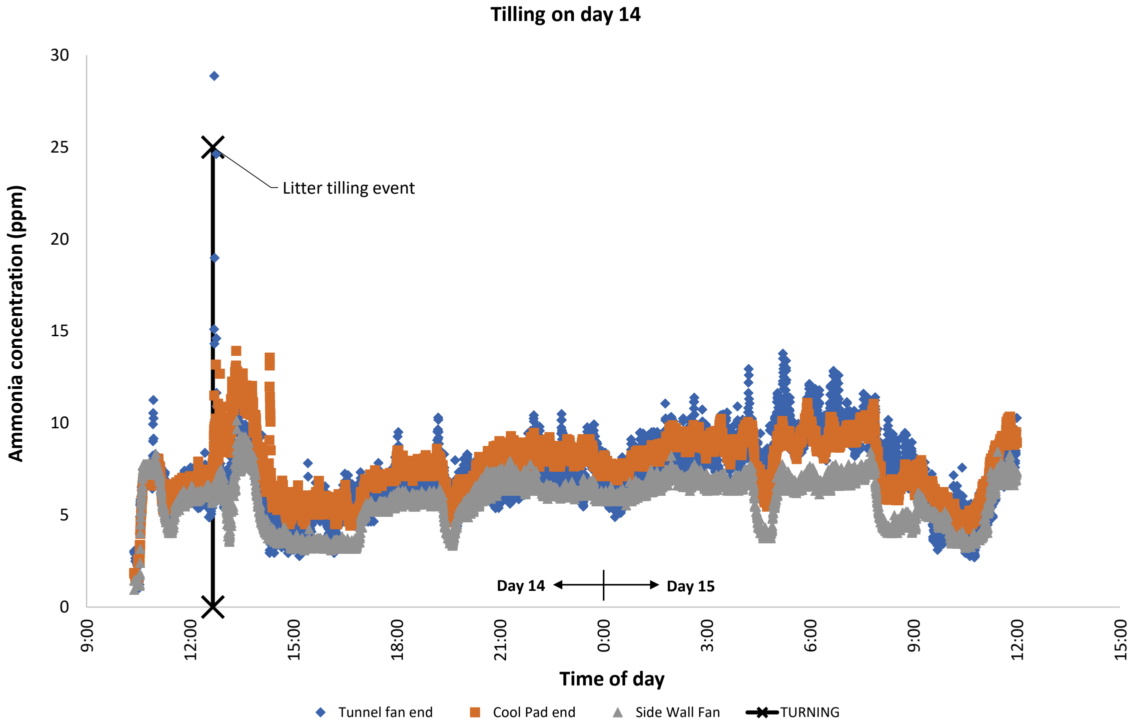


Figure 76. Ammonia concentration (ppm) measured in the poultry shed at Farm A1 when litter was tilled on day 14 of the grow-out (July 2021).

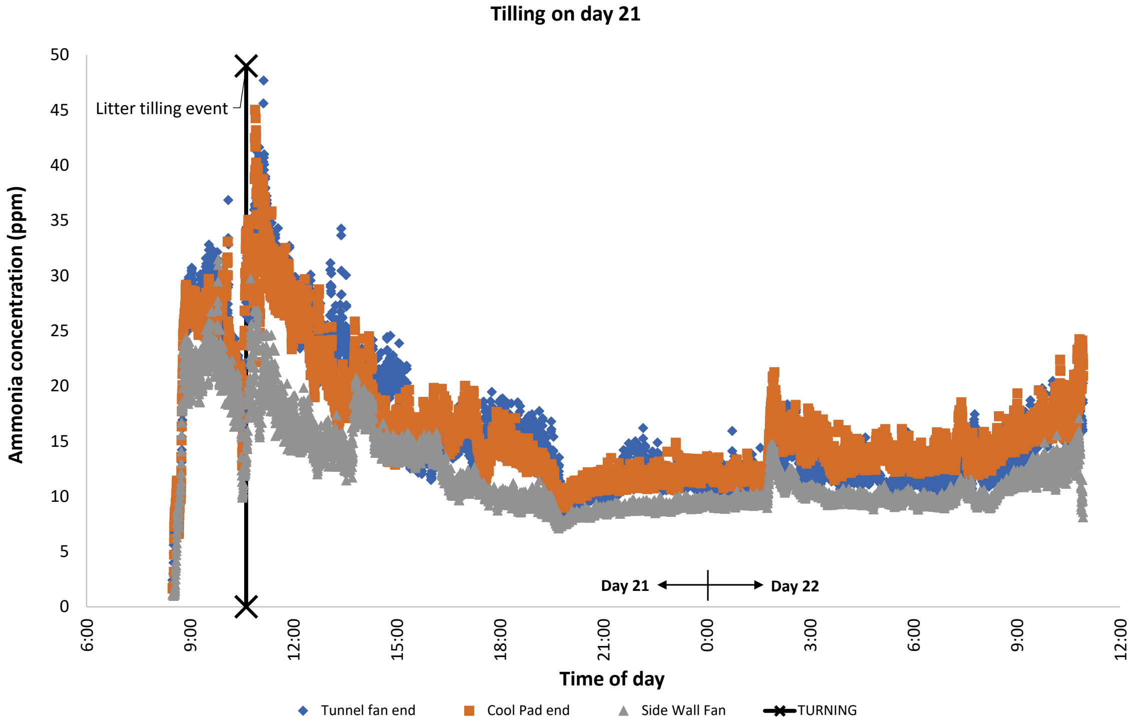


Figure 77. Ammonia concentration (ppm) measured in the poultry shed at Farm A1 when litter was tilled on day 21 of the grow-out (July 2021).

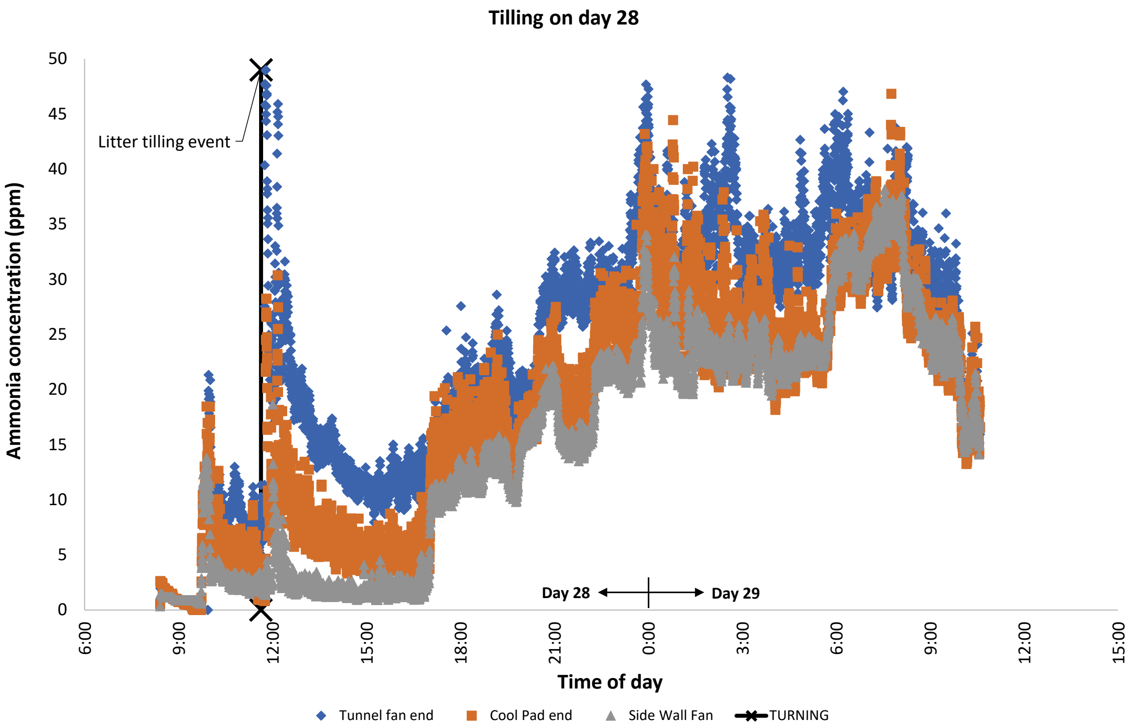


Figure 78. Ammonia concentration (ppm) measured in the poultry shed at Farm A1 when litter was tilled on day 28 of the grow-out (July 2021).

Farm A2

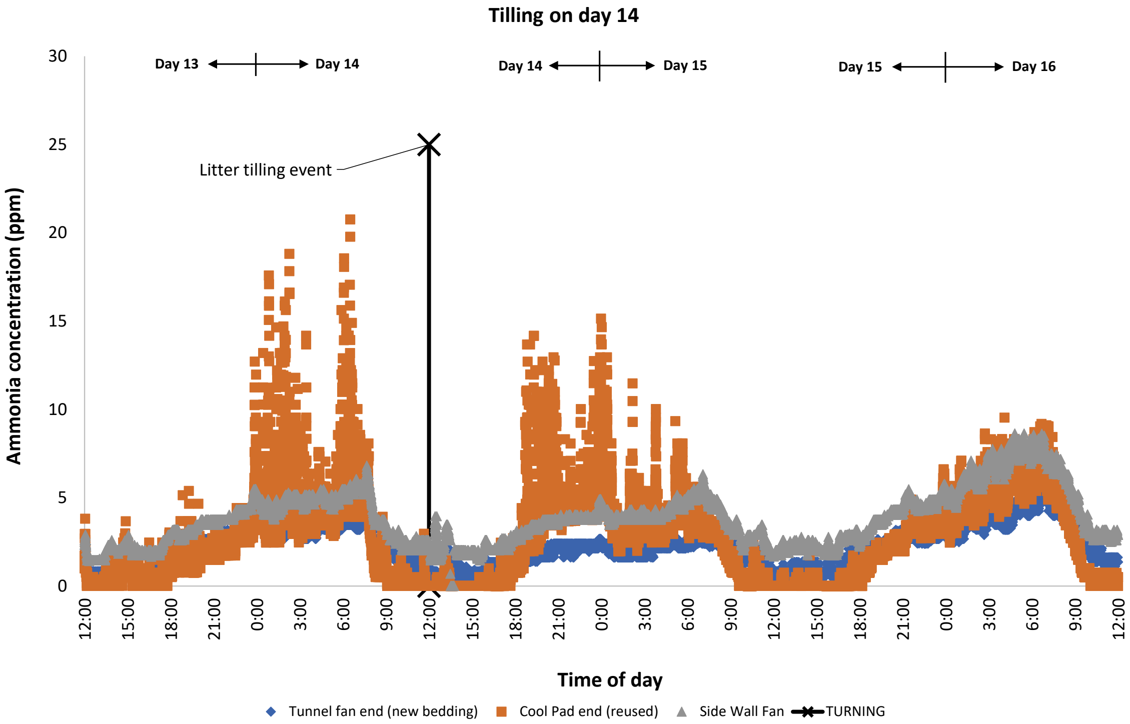


Figure 79. Ammonia concentration (ppm) measured in the poultry shed at Farm A2 when litter was tilled on day 14 of the grow-out (September 2021).

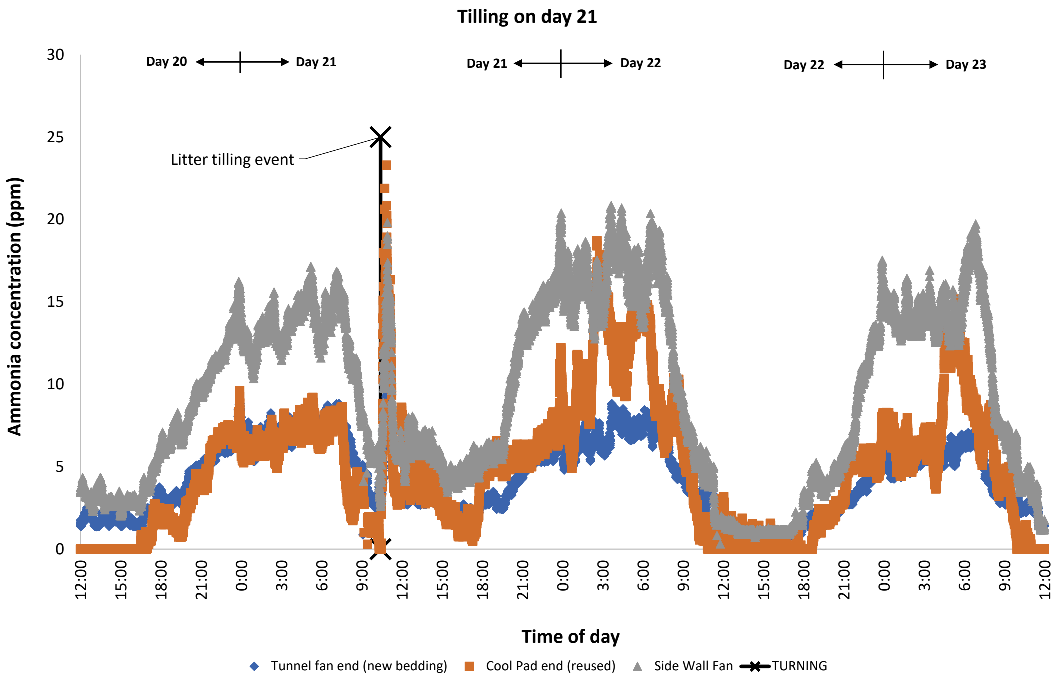


Figure 80. Ammonia concentration (ppm) measured in the poultry shed at Farm A2 when litter was tilled on day 21 of the grow-out (September 2021).

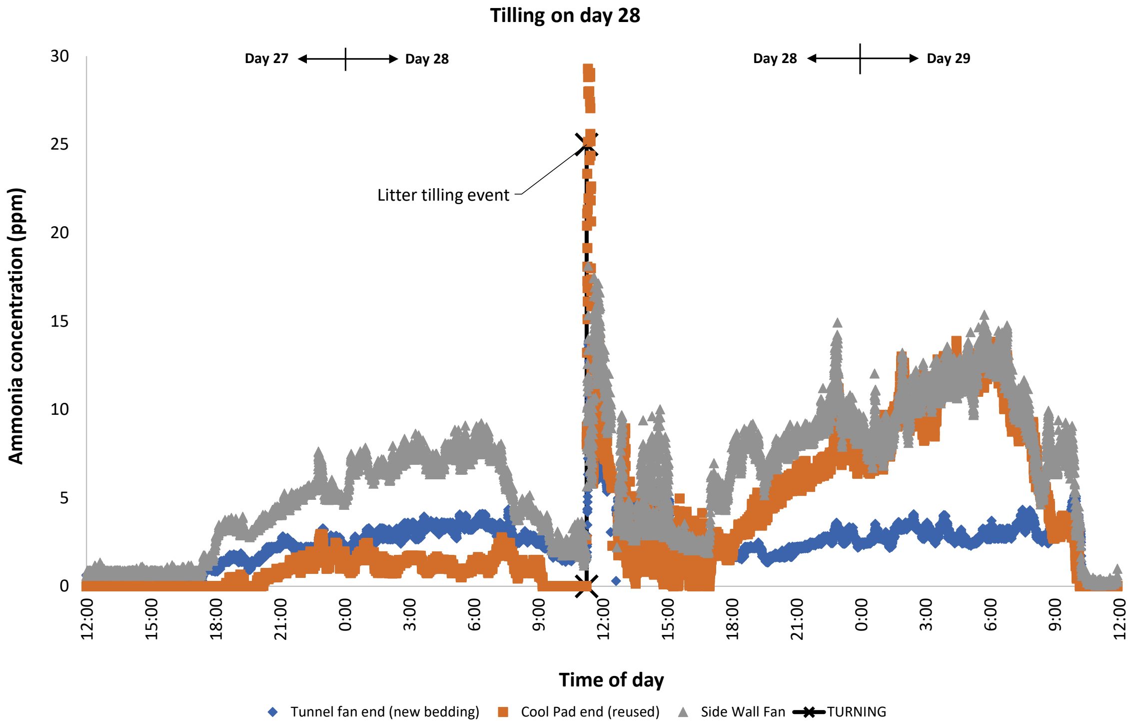


Figure 81. Ammonia concentration (ppm) measured in the poultry shed at Farm A2 when litter was tilled on day 28 of the grow-out (September 2021).

Farm B

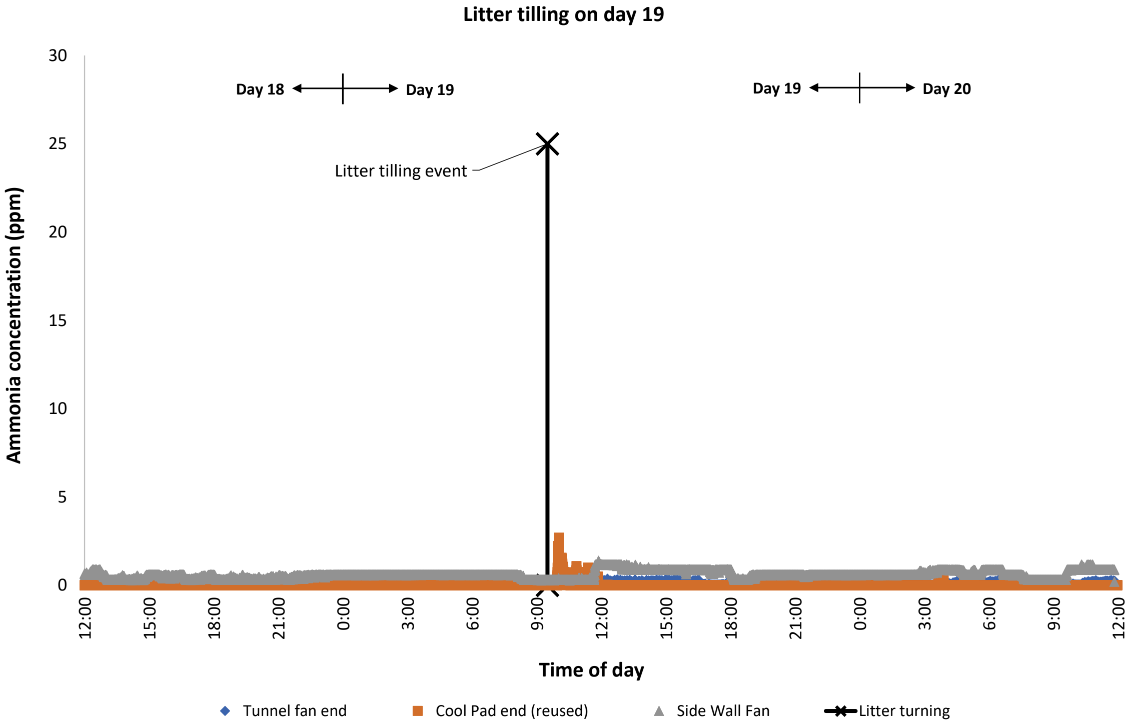


Figure 82. Ammonia concentration (ppm) measured in the poultry shed at Farm B when litter was tilled on day 19 of the grow-out (October 2021).

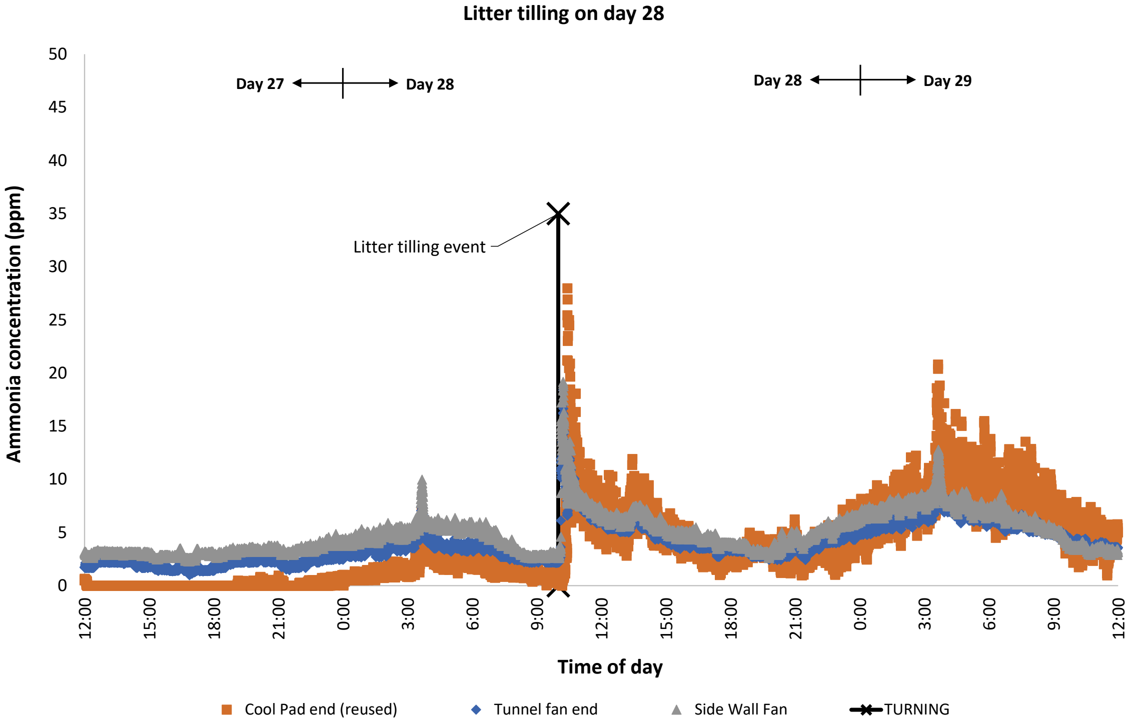


Figure 83. Ammonia concentration (ppm) measured in the poultry shed at Farm B when litter was tilled on day 28 of the grow-out (October 2021).

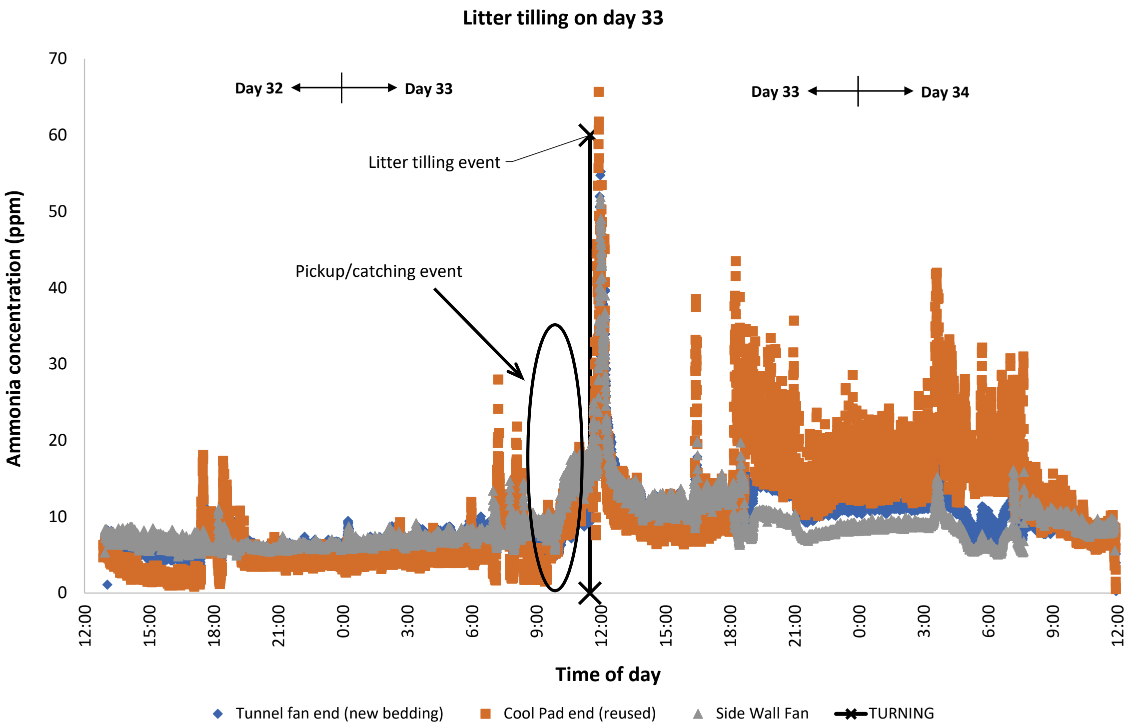


Figure 84. Ammonia concentration (ppm) measured in the poultry shed at Farm B when litter was tilled on day 33 of the grow-out (November 2021).

Farm C

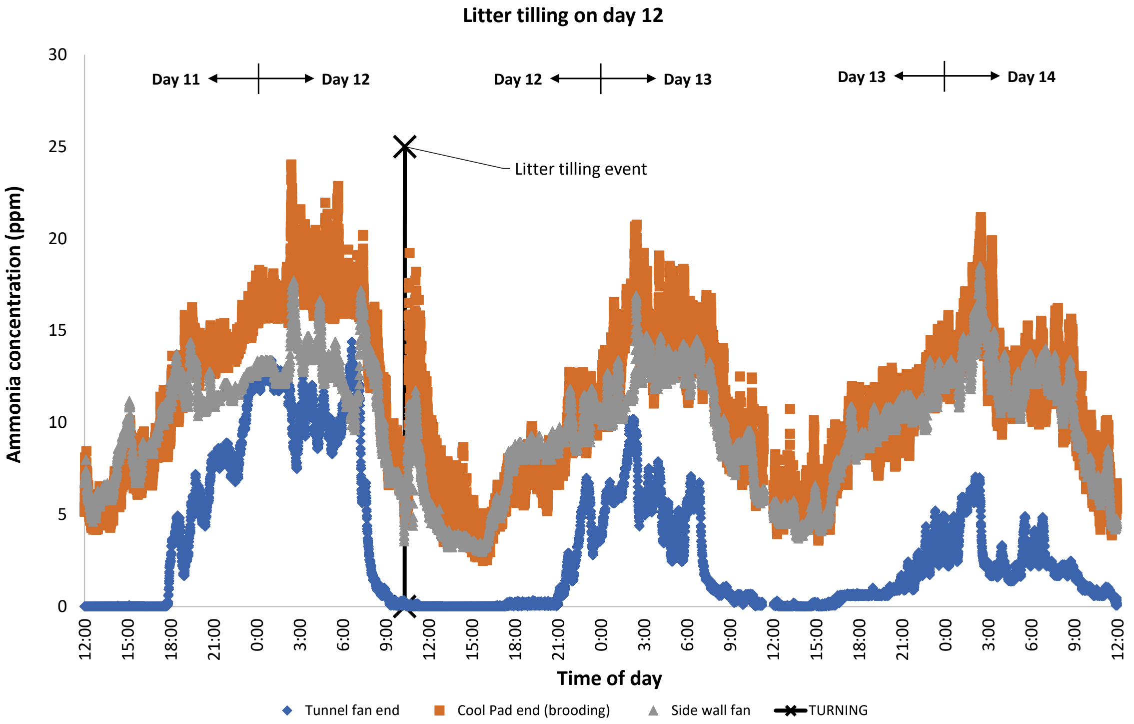


Figure 85. Ammonia concentration (ppm) measured in the poultry shed at Farm C when litter was tilled on day 12 of the grow-out (April 2022).

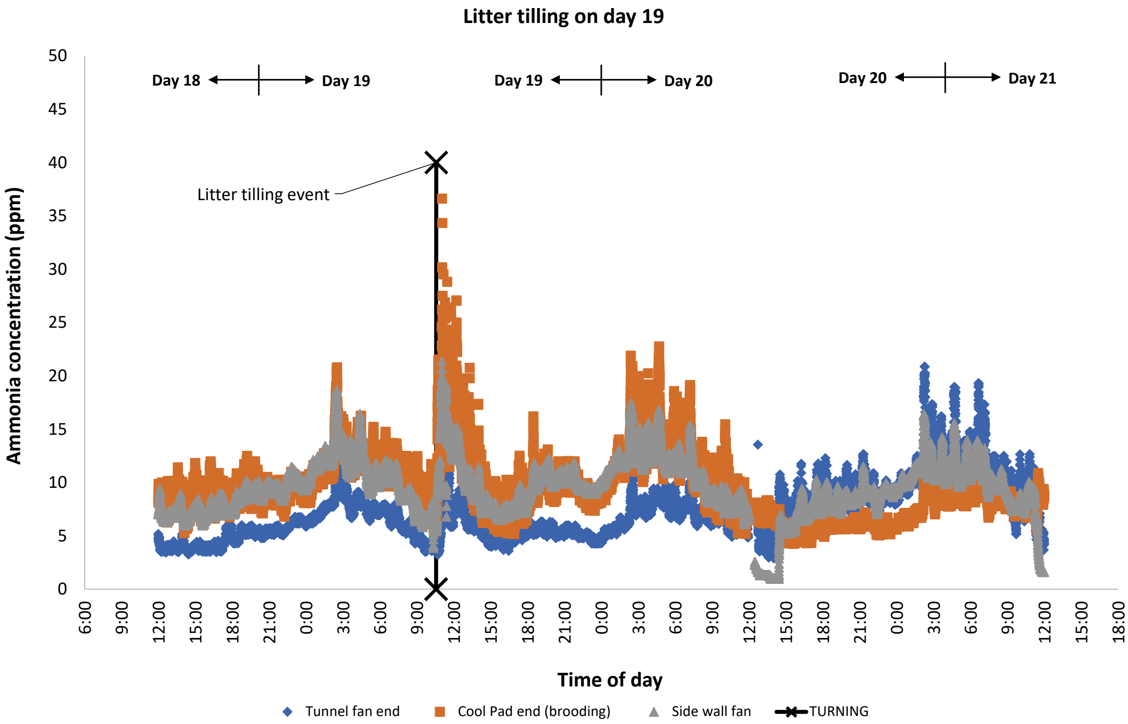


Figure 86. Ammonia concentration (ppm) measured in the poultry shed at Farm C when litter was tilled on day 19 of the grow-out (April 2022).

Farm D1

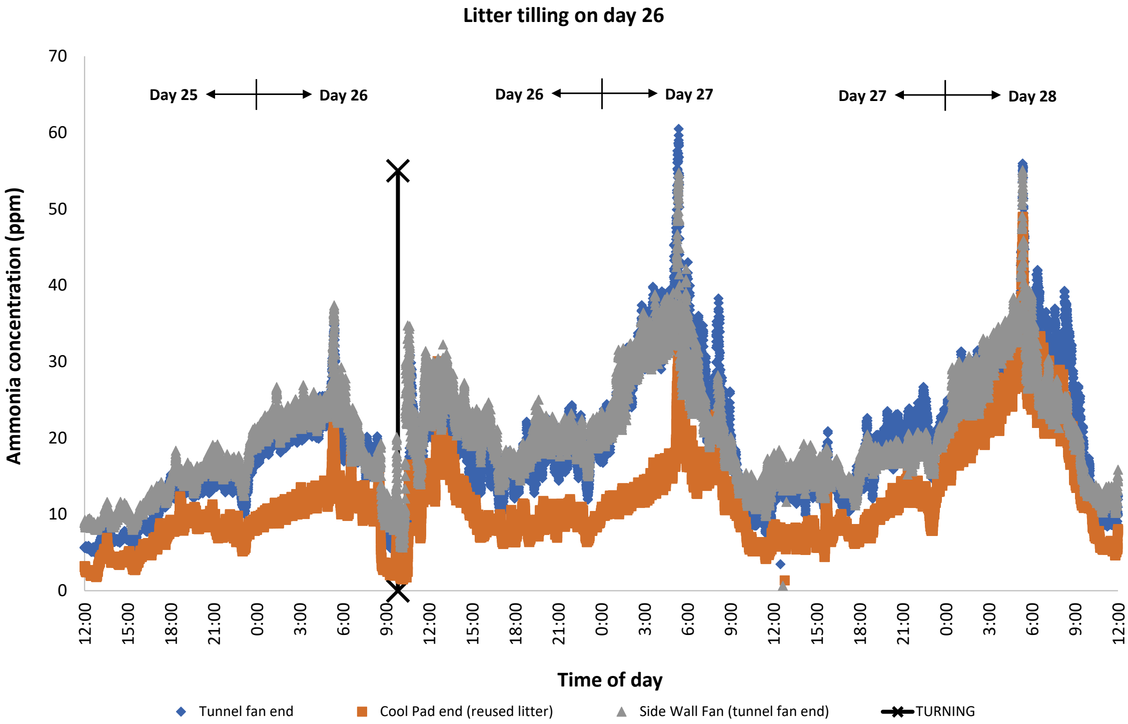


Figure 87. Ammonia concentration (ppm) measured in the poultry shed at Farm D1 when litter was tilled on day 26 of the grow-out (April 2022).

Farm D2

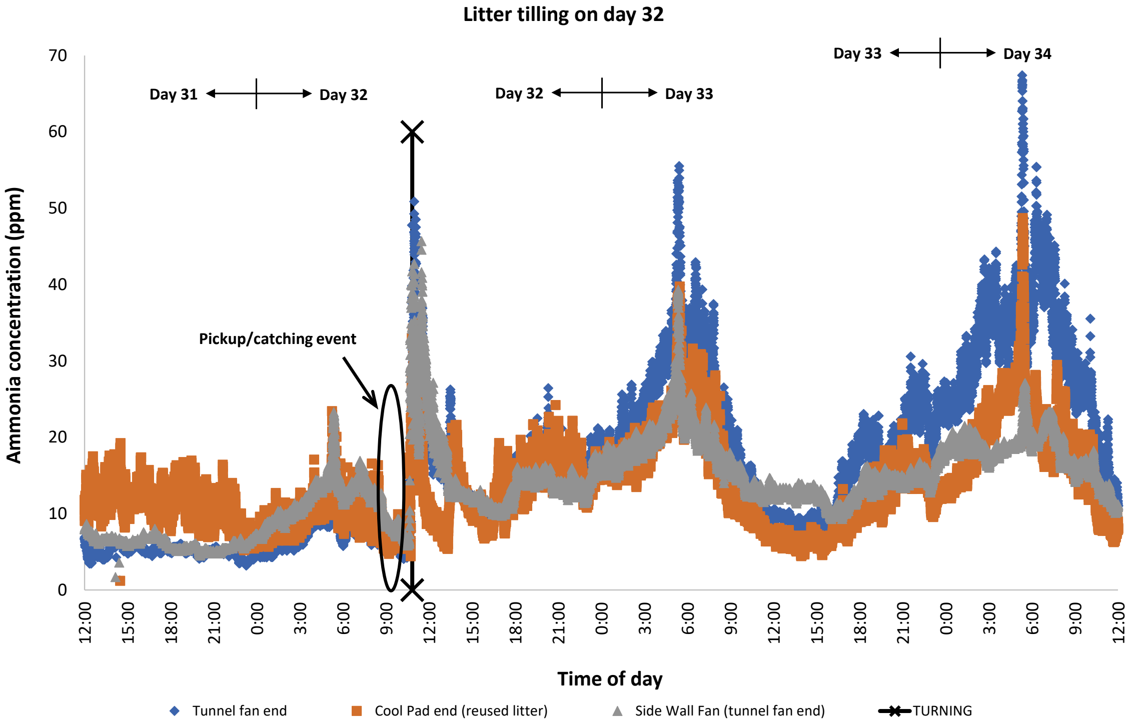


Figure 88. Ammonia concentration (ppm) measured in the poultry shed at Farm D2 when litter was tilled on day 32 of the grow-out (May 2022).

Appendix 4 – In-shed carbon dioxide concentration data

Farm A1

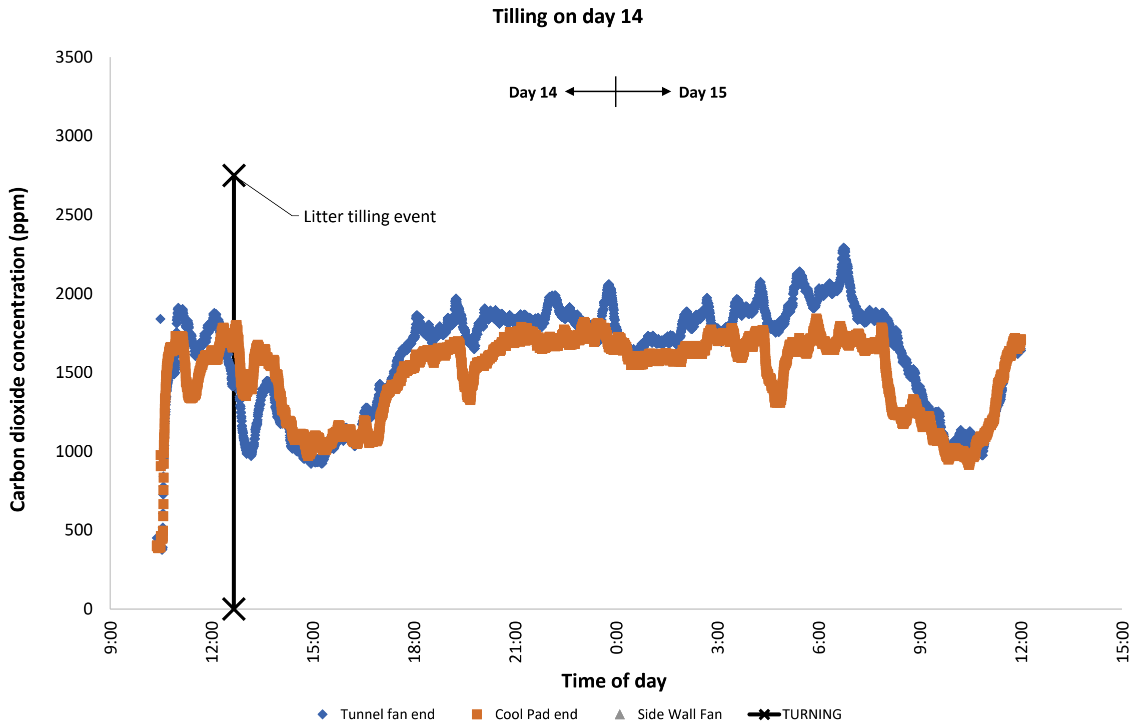


Figure 89. Carbon dioxide concentration (ppm) measured in the poultry shed at Farm A1 when litter was tilled on day 14 of the grow-out (July 2021).

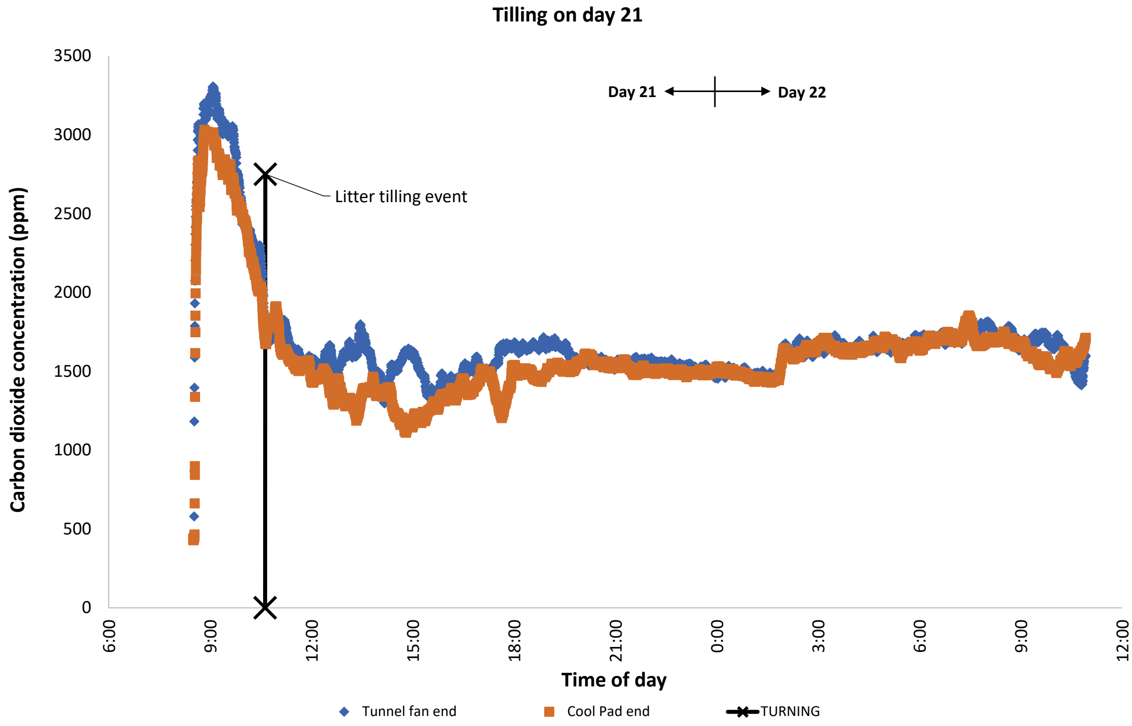


Figure 90. Carbon dioxide concentration (ppm) measured in the poultry shed at Farm A1 when litter was tilled on day 21 of the grow-out (July 2021).

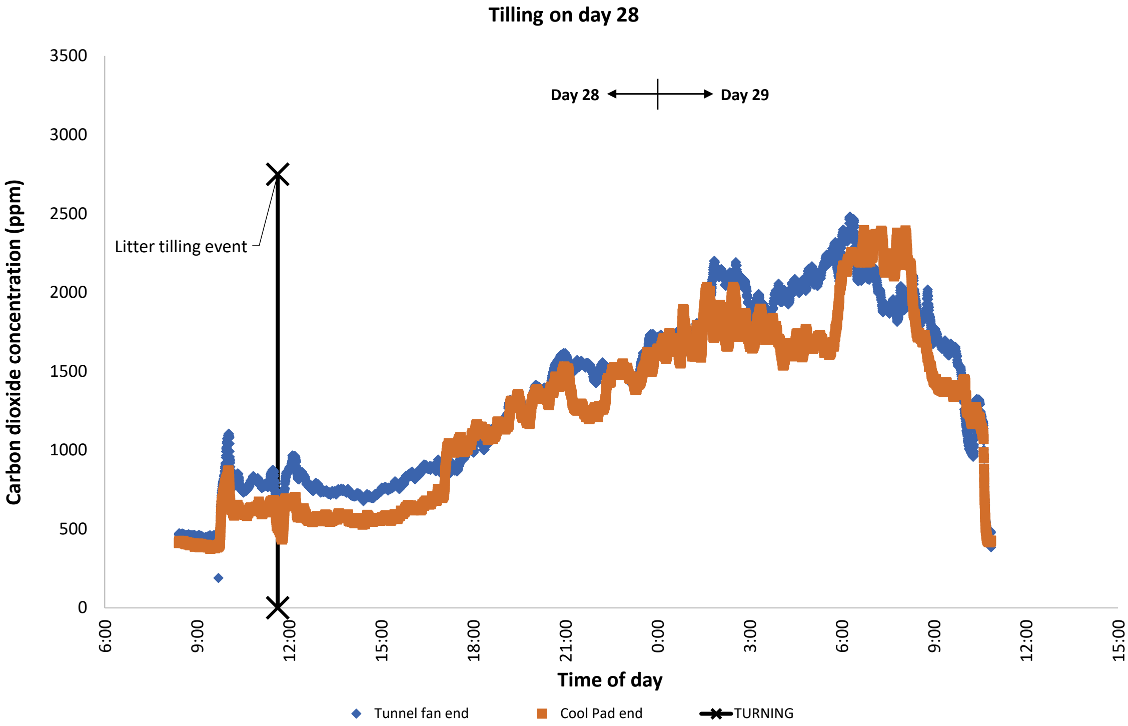


Figure 91. Carbon dioxide concentration (ppm) measured in the poultry shed at Farm A1 when litter was tilled on day 28 of the grow-out (July 2021).

Farm A2

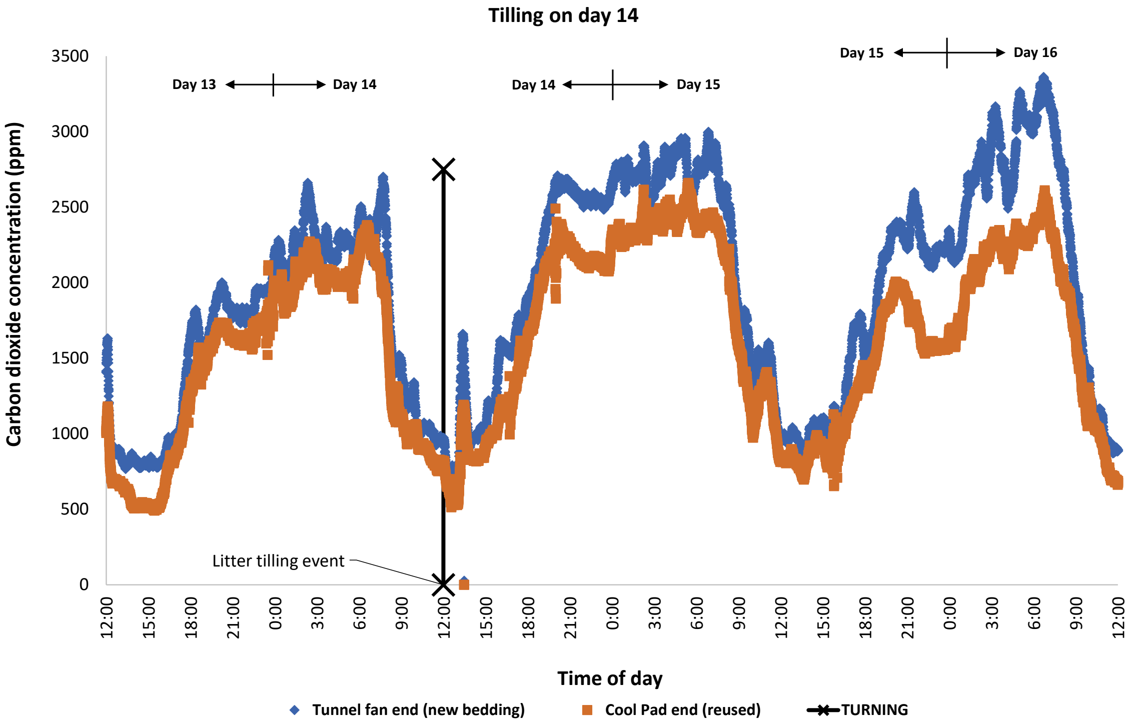


Figure 92. Carbon dioxide concentration (ppm) measured in the poultry shed at Farm A2 when litter was tilled on day 14 of the grow-out (September 2021).

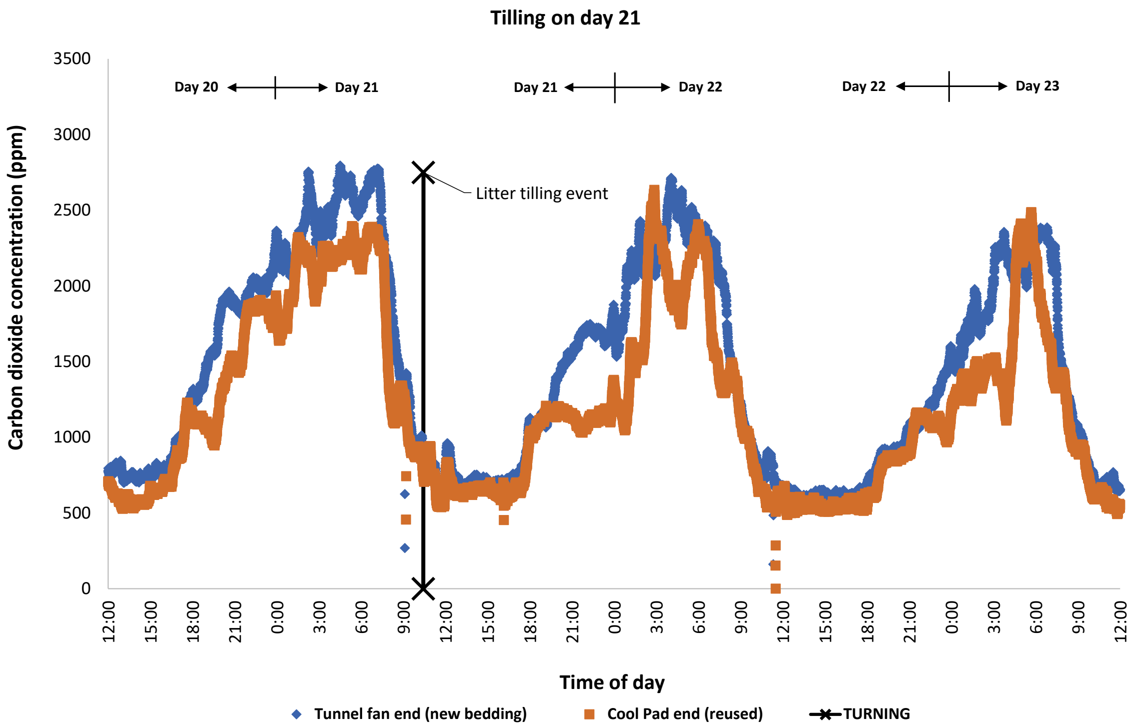


Figure 93. Carbon dioxide concentration (ppm) measured in the poultry shed at Farm A2 when litter was tilled on day 21 of the grow-out (September 2021).

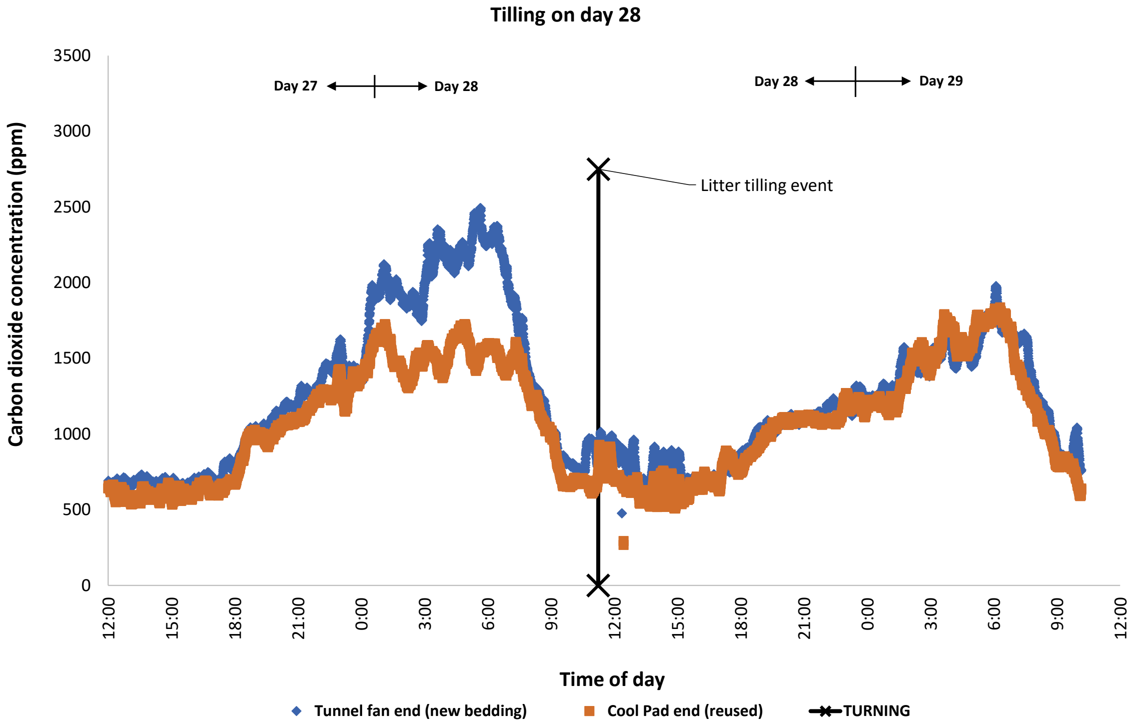


Figure 94. Carbon dioxide concentration (ppm) measured in the poultry shed at Farm A2 when litter was tilled on day 28 of the grow-out (September 2021).

Farm B

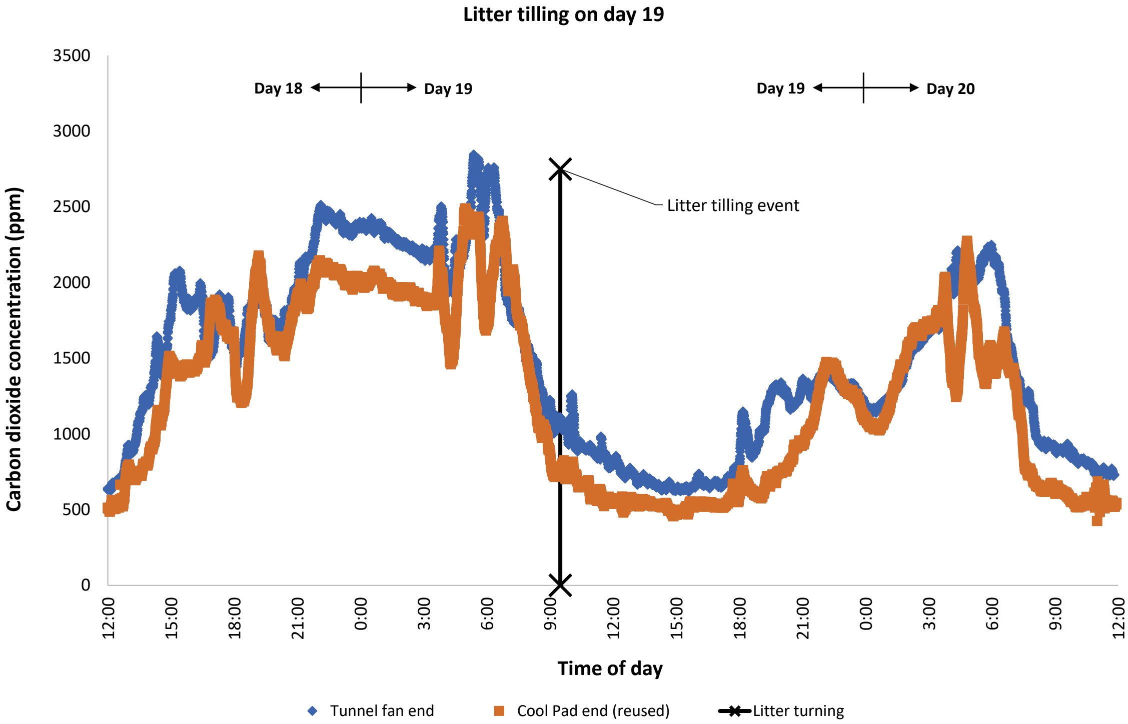


Figure 95. Carbon dioxide concentration (ppm) measured in the poultry shed at Farm B when litter was tilled on day 19 of the grow-out (October 2021).

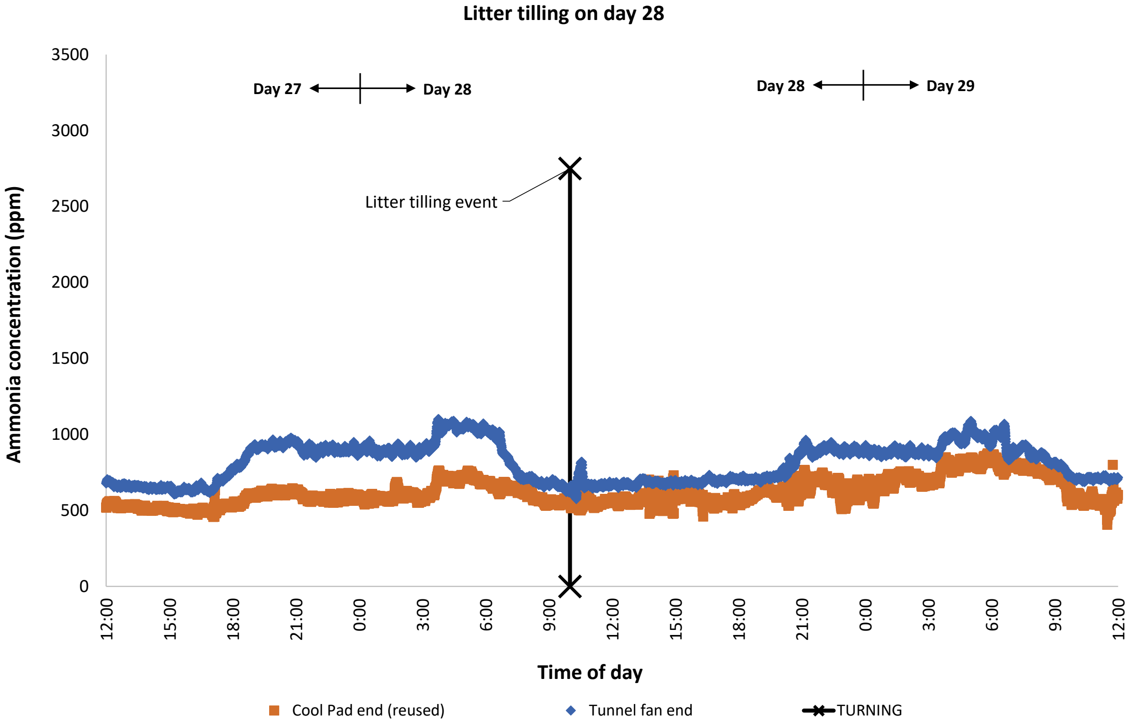


Figure 96. Carbon dioxide concentration (ppm) measured in the poultry shed at Farm B when litter was tilled on day 28 of the grow-out (October 2021).

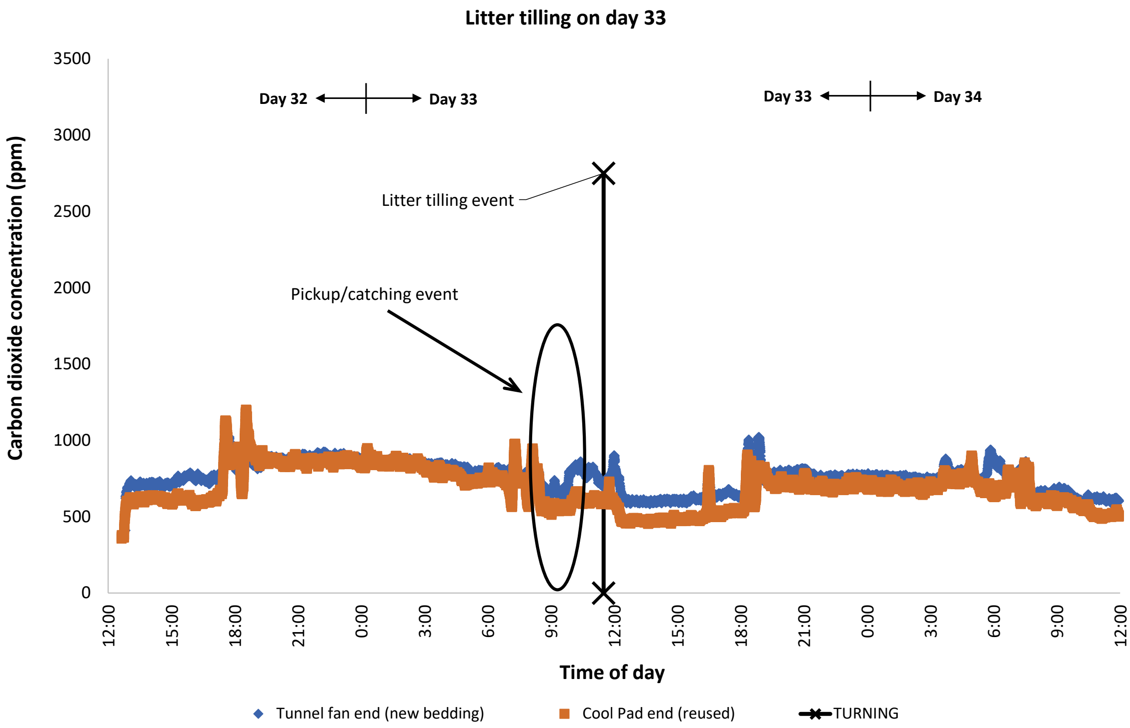


Figure 97. Ammonia concentration (ppm) measured in the poultry shed at Farm B when litter was tilled on day 33 of the grow-out (November 2021).

Farm C

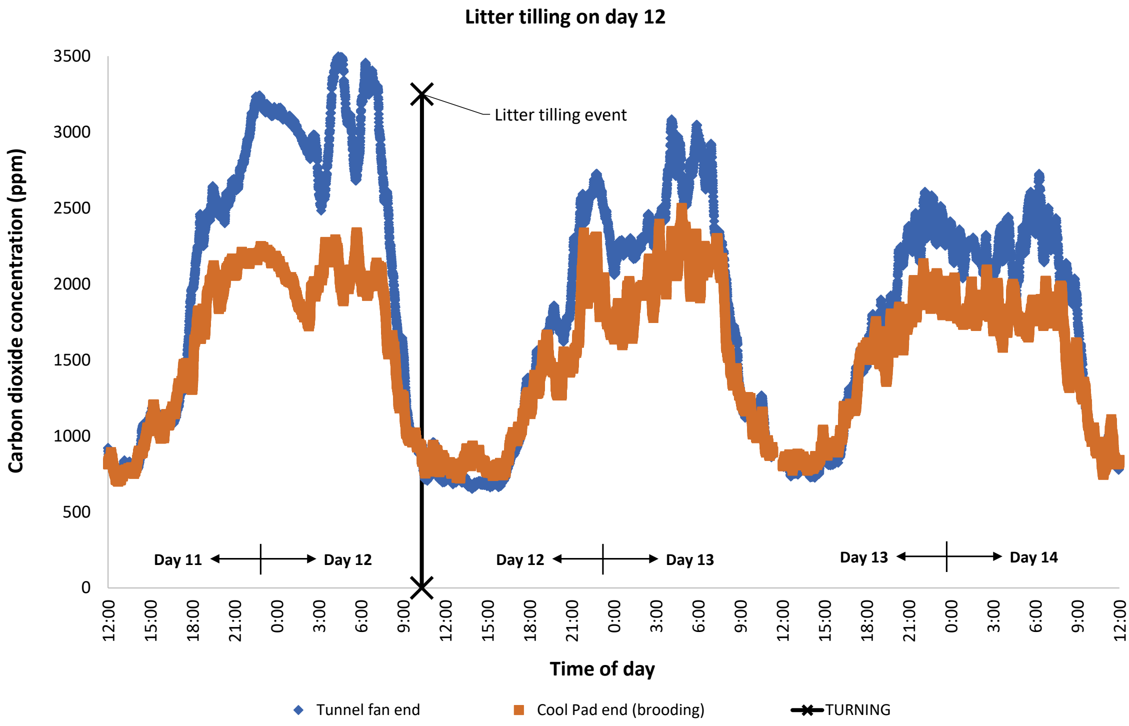


Figure 98. Carbon dioxide concentration (ppm) measured in the poultry shed at Farm C when litter was tilled on day 12 of the grow-out (April 2022).

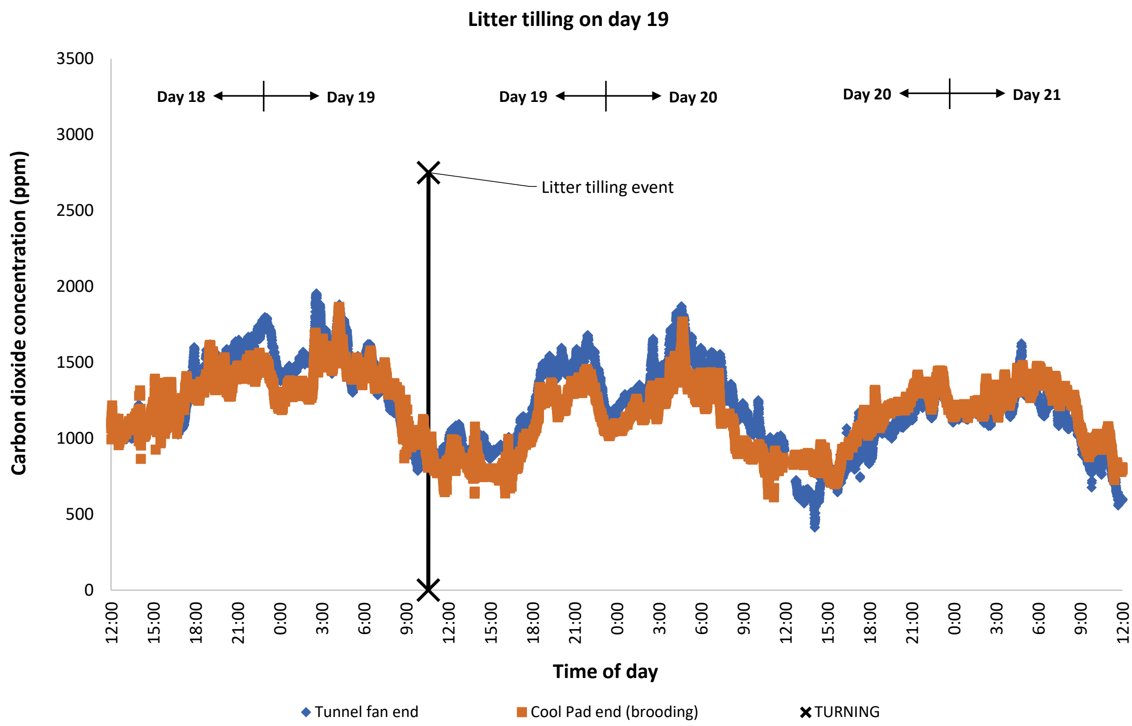


Figure 99. Carbon dioxide concentration (ppm) measured in the poultry shed at Farm C when litter was tilled on day 19 of the grow-out (April 2022).

Farm D1

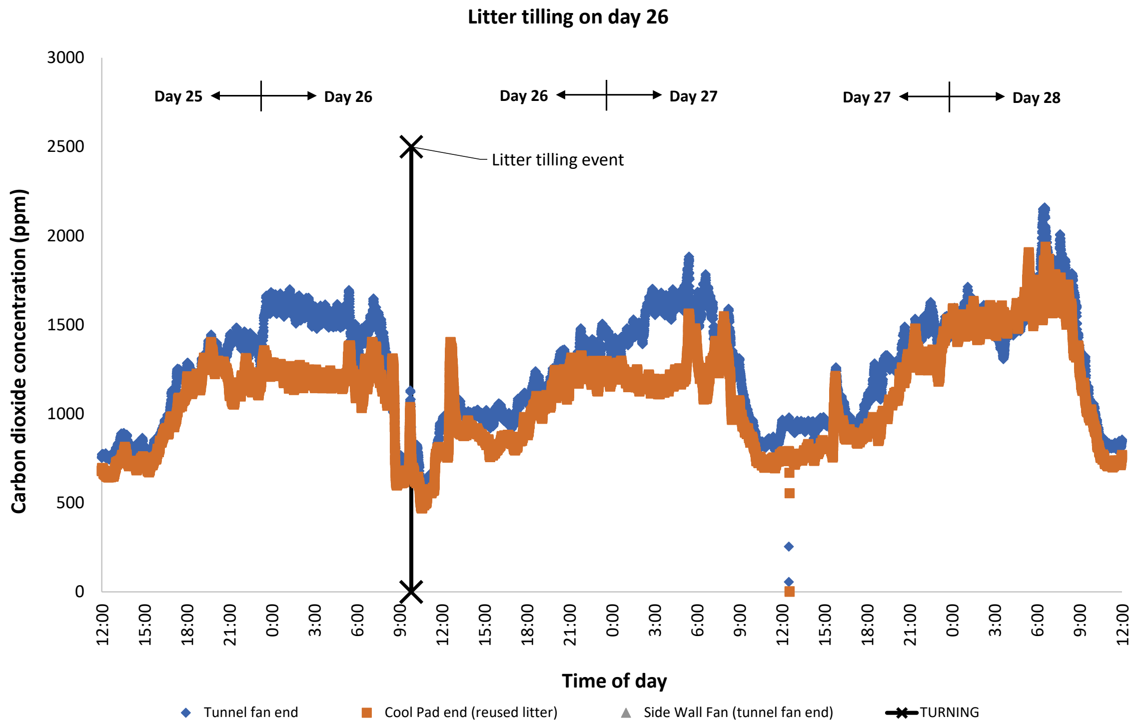


Figure 100. Carbon dioxide concentration (ppm) measured in the poultry shed at Farm D1 when litter was tilled on day 26 of the grow-out (April 2022).

Farm D2

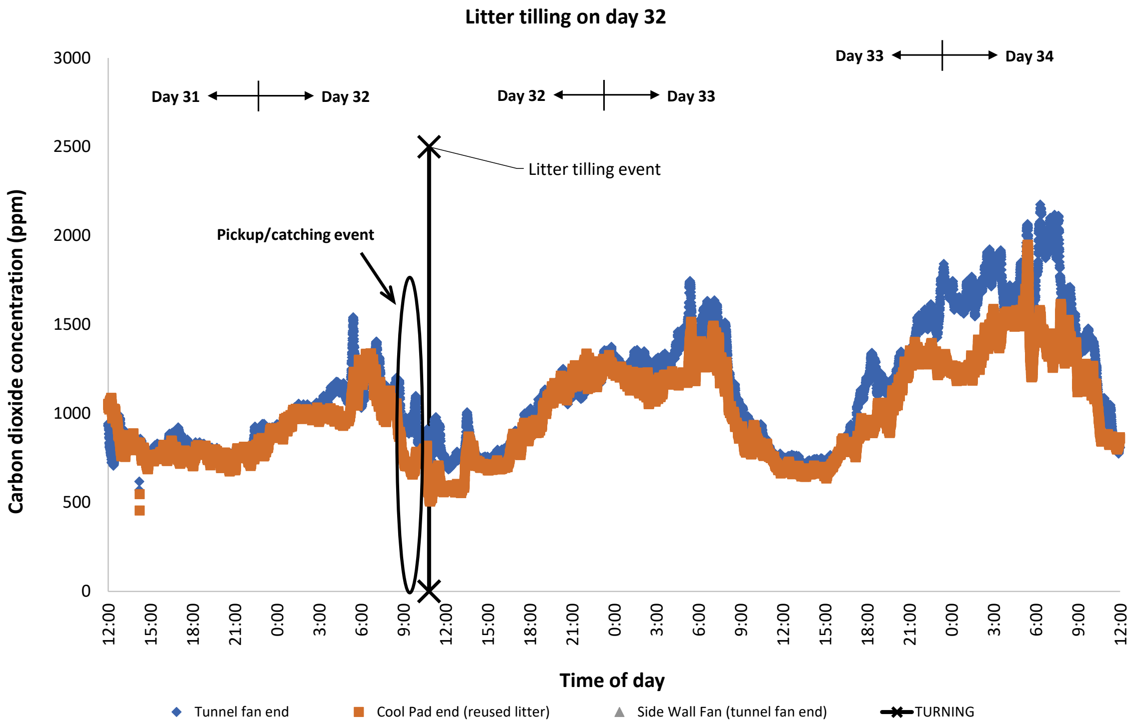
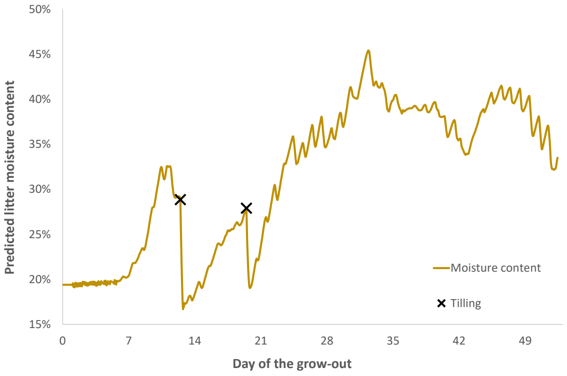
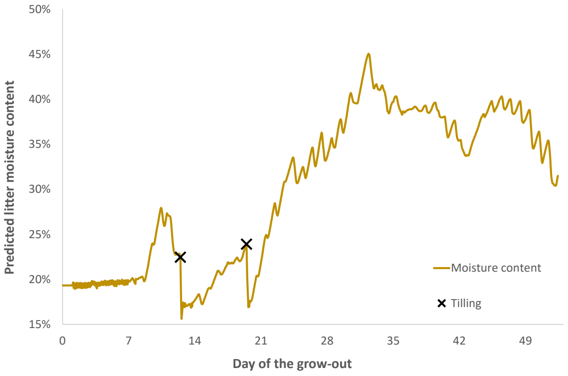


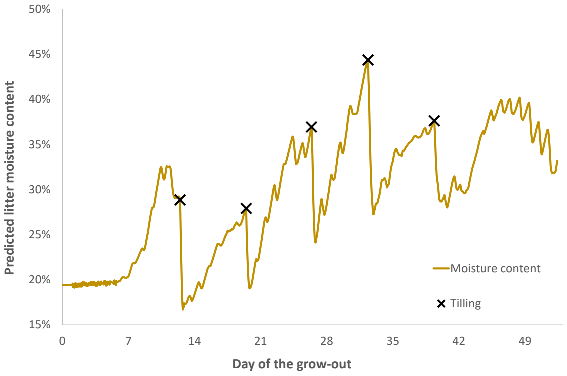
Figure 101. Carbon dioxide concentration (ppm) measured in the poultry shed at Farm D2 when litter was tilled on day 32 of the grow-out (May 2022).

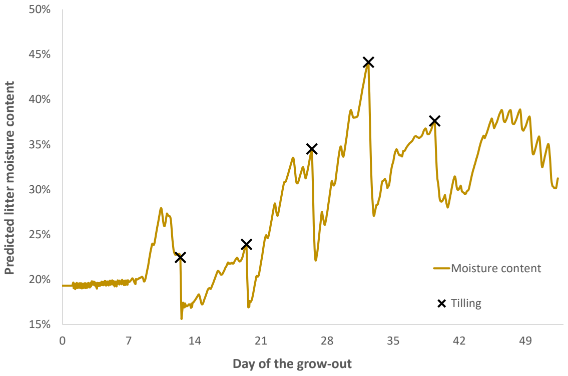
Appendix 5 – Litter moisture model outputs of simulated alternative management practices

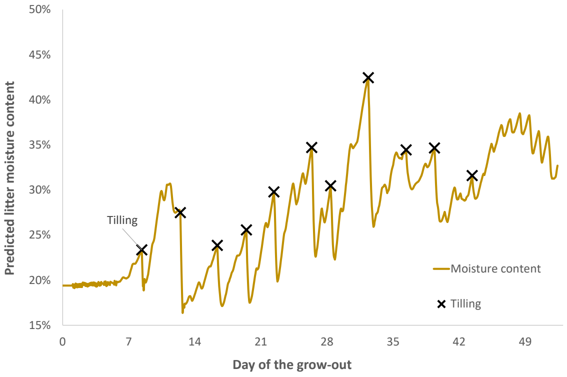
Farm A

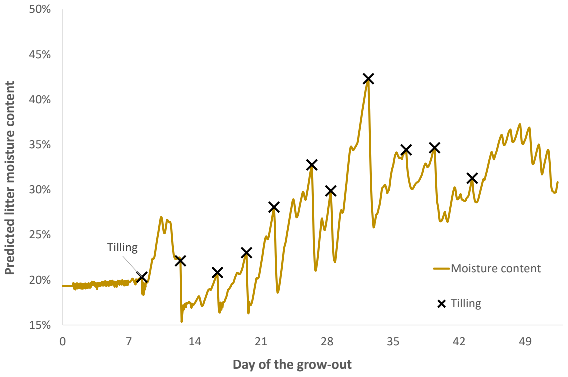

Modelling based on collected data


Simulated: Circulation fans

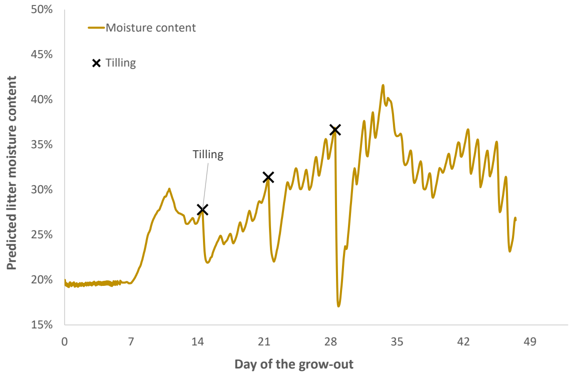

Simulated: Weekly tilling

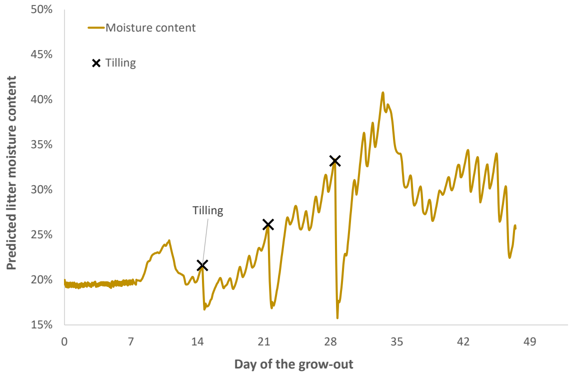

Simulated: Weekly tilling plus circulation fans

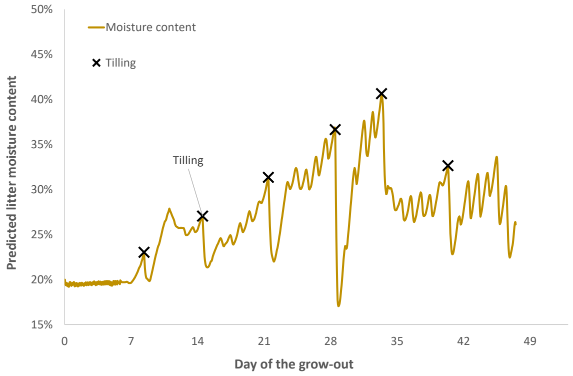

Simulated: Twice weekly tilling

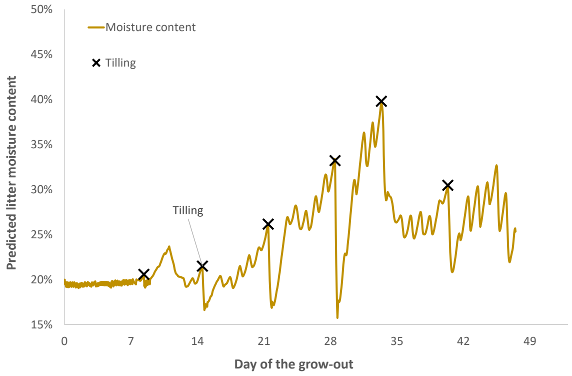

Simulated: Twice weekly tilling plus circulation fans

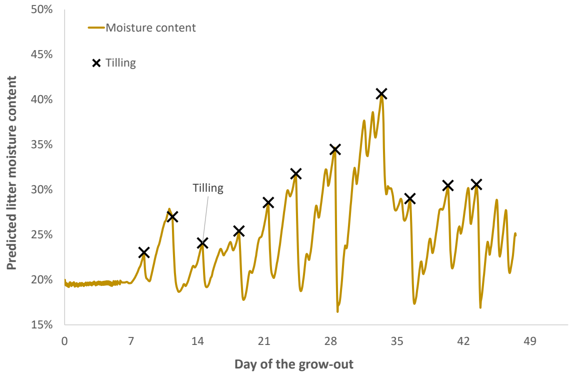
Farm B

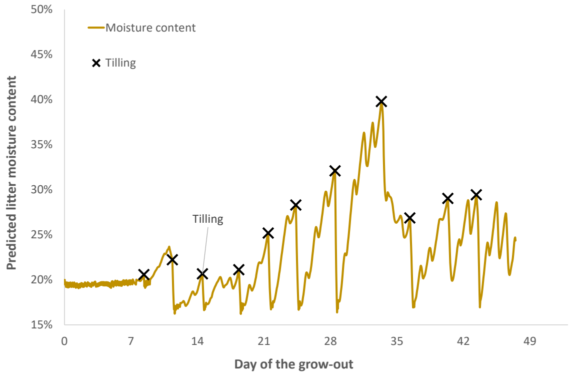

Modelling based on collected data


Simulated: Circulation fans


Simulated: Weekly tilling


Simulated: Weekly tilling plus circulation fans


Simulated: Twice weekly tilling


Simulated: Twice weekly tilling plus circulation fans

AgriFutures®
Chicken Meat

Litter management to support chicken meat production and industry growth

by Mark Dunlop and Claire-Marie Pepper
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