Haystack Fire Prevention

This Food Agility CRC project identified and reviewed the data essential to understanding haystack degradation as a precursor to fires, and how to process that data so that it can be transmitted through the existing limitations of satellite technologies.

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Myriota: Paul Sheridan, Steve Winnall & Scott Cramer

CSU: John Broster, Imtiaz Chowdhury & Joe Moore

Food Agility CRC: Professor David Lamb, Dr Mick Schaefer, Lucy Hickman, Christopher Komorek

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PROJECT DESCRIPTION

This project exists to alert farmers when their haystacks are likely to catch fire. This results in claims worth ~$1.8m per annum, and additional psychological damage. We believe that a haystack monitoring product will reduce haystack fire claims and increase IAG's footprint in Agri business across Australia.

2. End-User Problem(s)

- One hot bale can destroy a whole haystack, or worse. Haystack fires usually lead to total loss, thus it is crucial to proactively mitigate the potential fire risk.
- Haystacks fires are spontaneous and hard to predict.
- Haystacks are dense. Heat in specific parts of the bale can go undetected unless the sensor is in the right spot.
- Haystack losses are not just financial, but also psychological.
- Haystack fires cost farmers $1.9m per annum (sourced through IAG claims)

Today's alternative solutions

- Using crowbars to manually test hay condition
- Cellular solutions
- Wi-Fi connected detection kits back to modems

4. Our Solution

- Model – to determine hay degradation thresholds (green, orange, red)
- Suggested tech stack (i.e. recommended sensor configuration and placement)
- UX to display information to customer

5. Key Results
(what can be measured to demonstrate project impact)

1. Model and alert system tested on 4 sites (CSU and 3 IAG customers)
2. Model accurately identifies hay degradation bands

3. Unique Value Proposition

- We will alert you that your hay is degrading and facing an increased chance of fire risk.

12. Highest Risk Assumptions

1. It is possible to model haystack fires
2. End-users can prevent a fire if alerted that it is likely to happen
3. Devices can be built for less than cost of insurance premium

6. Partners + Team

- Myriota – communications technology
- IAG – customer access
- CSU – researcher and modelling

Team

- Nicholas Carabine – IAG Firemark – project lead
- John Broster - CSU research lead
- Tom Boot – Myriota, project support
- Shen Lu – IAG Firemark, insurance advisory

7. Pathways to Scale / Impact

- Commercialised through Myriota (likely by installing Myriota hardware in other partners equipment)
- Promotion, distribution and sale will be through channel sales (i.e. through Suncorp, IAG etc)

1. End-Users

- Farmers with haystacks on their properties

Early-Adopter

- 3 IAG customers in NSW

8. Expected Contributions
(Cash & In-kind)
(list cash and in-kind contributed by each partner)

- $91,670: IAG
- $91,670: CSU
- $91,660: Food Agility
- 1.02 FTE (Myriota, in-kind))

TOTAL: $275k cash

10. Data Sets

- CO_2, Temperature and moisture data – to be created by sensors
- Possible: Weather – existing – to look at modelling in different climatic conditions
- Possible: Geospatial – existing – to look modelling in different climatic conditions

11. Research Questions

- What are the hay conditions (e.g.. temperatures, C02 and moisture) for the haystacks to ignite?
- Do these conditions vary depending on haystack variety?
- Where is the best place in a haystack to place the sensor?
- What is the best technology configuration (sensors) needed to alert a customer?

9. Expected Project Costs
(Cash & In-kind)
(list cash and in-kind contributed by each partner)

- $205,000: Research Trials (CSU)
- $40,000: Hardware/components (Myriota)
- $30,000: Food Agility (program support/management)
- In-kind: ~1 FTE to support product integration (Myriota)

TOTAL: $275k cash (+1 FTE in-kind)

PROJECT PARTNERS

EXECUTIVE SUMMARY

Background:

Hay production is a $2.5 billion enterprise for Australian farmers, and the spontaneous combustion of hay is a significant economic and health risk for producers. Alongside the variety of factors, haystacks are a complex and detailed process, and involve the producers' ability to safely store and manage their hay.

Throughout 2021, alongside business leaders at Insurance Australia Group, the team at IAG Firemark Ventures conducted a forced-ranking of use-cases in the Agri field. Coming out on top of this was haystack temperature monitoring, which, with the power of Internet of Things, and the ability to leverage the investment in portfolio company, Myriota, was a possibility to explore.

After a few months of strategic planning, a group of focused trial stakeholders was activated, which was to be done alongside Food Agility. The consortium included Charles Sturt University, Myriota and IAG. From December 2021 to May 2023, the trial was able to investigate a Haystack temperature monitoring solution and explore the ways in which haystack fires can occur.

Aims / Objectives:

The outcome of the project is as follows:

This project exists to alert farmers when their haystacks are likely to catch fire. Haystack fires result in multi-million-dollar claims per annum, and additional psychological damage. We believe that a haystack monitoring product will reduce haystack fire claims and increase IAG's footprint in Agri business across Australia.
In terms of objectives:

1. A successful haystack monitoring solution satisfying insurance customer needs
2. Identify key data points and modelling for haystack fire risk prediction
3. Identify pathway to scale to more customer opportunities (related insurances outcomes)

Methodology:

The research throughout this project was important as it evaluated the sustainability of a current commercial sensor to monitor hay temperature. The ability to gain an improved understanding of the process involved in the spontaneous combustion of hay was at the forefront of the research and methodology undertaken throughout the trial. The major question posed: how can the data received throughout the process help us to evaluate a new sensor for monitoring hay temperature?

The research findings will be of great benefit to the entire hay industry – growers, processors, exporters and insurers.

When looking at the problem, the spontaneous combustion of hay is a significant economic and health risk for consumers. This leads to complex processes involved in the ability to safely store and manage hay.

There are many ways in which haystack fires are caused, these include the size of the body of material, high ambient temperatures, thermal insulations, fibrous natures and porosity of plant materials, stacking temperatures and a period of time being undisturbed.
We focussed particularly on spontaneous combustion, which was found throughout the trial to occur within six weeks of bailing. A major factor for the spontaneity is the interaction of moisture and sugar content, whilst other factors include bale size and type, storage methods and the environmental conditions.

Throughout the trial, a proof-of-concept device was able to be developed by Myriota, alongside their supply-chain network. Once this was ready, the trial was activated in Wagga Wagga (NSW) on four properties. A successful trial date was also held at Charles Sturt University, where haystacks were lit on fire to test the technology. This led to partners agreeing that the trial should be expanded – and moved to include Victoria & Western Australia.
The dashboard capability was also developed alongside Myriota's supply-chain and allowed both trial members and trial participants to access the dashboard, allowing them to track the internal condition of the haystacks.

The above allowed the team at CSU to conduct their research in order to develop a greater understanding towards haystacks and why they may spontaneously combust.

Any results, key findings and / or insights:

Results:

- Device prototype built and deployed to at least 1 trial customer successfully (01/01)
- A digital online dashboard showing data captures from IoTs to farmers deployed to at least 1 trial customer (01/01)
- A model / risk score developed using data captured. A risk score threshold identified that can be used to alert farmer potential haystack fires (0.75/01)
- Successfully alerted farmers high haystack fire risks in time for them to action (0.5/01)
- Farmers are able to take actions to mitigate haystack fire risk leveraging the deployed devices, thus improves safety on farms and protects farmers from potentially larger infrastructure damage (i.e. machinery) and losses stemming from haystack fires. (01/01)

Key Findings / insights:

- The current commercial sensor was suitable for monitoring hay with some caveats (eg: mobile phone coverage)
- We gained a greater understanding of the influences on the process of combustion
- 50-60° C is a key temperature, hay can cool from this temperature with no nutritional loss
- Ambient air temperature plays a role in the maintenance of bale temperature.

Recommendations:

As a result of the research throughout the trial, we are able to recommend that a safe (green) temperature is below 49 °C, producers should monitor and take action as required (amber) for temperatures between 50 – 60°C degrees. It is worth noting that the maximum temperature during the trial was 65 °C, with a maximum temperature increase throughout the trial being 45.5 °C. We are yet to confirm what a critical (red) temperature is, so cannot recommend what this is.

It appears that 50-60 ° C is a critical value for initial temperature alerts as we have observed hay cooling down from this temperature but with differing impacts on quality. There are some caveats with this finding; these bales were not in large haystacks, but either individual bales or single rows stacked two high, so heat loss would be greater than in a stack, and secondly, ambient temperature and humidity may play a part in both the heating and

cooling of hay and also in the impacts high moisture and temperature may have on hay quality.
From the initial recommendations, CSU found that the Quanturi probes are a suitable method of measuring temperature in haystacks. The length of the probes is (40cm) results in the temperature sensor being buffered from outside fluctuations in temperature and therefore providing a more accurate reading of the actual internal temperature at the location where the combustion process is most likely to be initiated. This means that the probes need to be located such that the tip is not pushed towards the edge of a bale but centrally located.

Whilst the project group believes that we are still only scratching the surface, a positive start to research in this area has been made. Discovering what the critical temperature is will go a long way towards creating success.

In finishing, "*as our circle of knowledge expands, so does the circumference of darkness surrounding it"* Albert Einstein.

INDUSTRY IMPACT METRICS

Impact metric 1

This is a significant risk for IAG's agricultural customers, with haystack fires resulting not only in direct losses of haystacks and compromising the safety of farming communities, but also has the potential to impact upon surrounding infrastructure such as machinery, creating further disruption to farming operations and livelihoods.

Impact metric 2

The improved customer experience will enable timely quantitative data driven decisions. The ability to monitor the internal condition of a haystack will allow clients to make informed decisions by powered data, taking the guesswork out of outdated farming practices. This may lead to customers being more alert and knowledgeable.

Impact metric 3

The use of quantitative data, as opposed to qualitative data, will improve decision making processes. The ability to instil greater confidence In growers and processors would reduce industry stress.

IMPACT STATEMENTS

INDUSTRY PARTNER

Nicholas Carabine & Daniel Cawood, IAG

The haystack monitoring solution has the potential to provide increased safety for IAG customers. Introducing customers to the opportunity to monitor their haystacks with this emerging technology helps align with our purpose, 'Make your world a safer place'. The improved safety will also provide customers with a greater peace of mind, which can lead to psychological benefits, which are hard to quantify but are of huge importance.

Aside from the customer benefits, IAG as a business should see a reduction in haystack claims per year, which can be a multimillion dollar expense leading to improved risk mitigation and a reduced loss of commodity.

Haystack monitoring used to rely on outdated practices, but now has the opportunity to be transformed through this improved technology.

TECHNOLOGY PARTNER

Paul Sheridan & Steve Winnall, Myriota

Myriota is at the forefront of the Internet of Things (IoT) technology, using its space-based technology, low-cost long battery life hardware, and secure direct-to-orbit connectivity to extend IoT beyond the reach of terrestrial networks, globally. Myriota's mission is to deliver better outcomes for people and planet through IoT solutions that "just work", anywhere.

This Haystack project has enabled the Myriota team to engage deeply with the teams from IAG, CSU and Food Agility to consider the end-to-end requirements and commercial drivers relating to and the prevention of spontaneous haystack combustion. Understanding the critical elements and the science behind the internal chemical reactions and enabling the connectivity so that these valuable assets can be actively monitored, thereby decreasing the chance of an event occurring is leveraging our technology and mission exactly as envisaged.

The delivery of the critical data to enable the ability to decide how best to act will undoubtedly provide better outcomes both upstream and downstream once commercialisation occurs.

RESEARCH PARTNER

John Broster, Imtiaz Chowdhury & Joe Moore – Charles Sturt University (CSU)

The Haystack Fire Prevention project, in partnership with Myriota and IAG, aligns with the University's mission and its research institutions and initiatives. By providing end-users of this technology with quantitative data for decision-making processes in agriculture, we can enhance management practices. This will ultimately lead to more profitable and sustainable producers, thereby improving the availability of food and fibre for the general public.

END-USER PROFILE

Jack Dalbosco, Dalbosco Bros

Jack joined the family business (cattle farming) when he finished school in 2015 and has taken on the responsibility of finding new and improved ways to conduct farming practices (where applicable). As a result, the haystack monitoring solution has been something of huge interest:

"It will be of great value, particularly once the tipping point is known (red in the RAG status). As soon as that has been worked out, it will be incredible, and to be able to look at it on your device, and not have to physically monitor, will make for a great advantage."

Running a large cattle farm with many day-to-day responsibilities makes for busy days, so having access to this up-and-coming technology will help save time and increase productivity: *"It's one less thing to worry about. We bail other people's hay as well, so to not worry about checking ours often, would be a great help".*

The Dalbosco farm has also had some experience with Haystack fires: *"Having had very close calls in the past on our own property, and knowing of other situations on other farms, this will help alleviate those worries, and is something we will be recommending if it becomes an off the shelf solution".*

OBJECTIVES

1. A successful haystack monitoring solution satisfying insurance customer need
2. Identify key data points and modelling for haystack fire risk prediction
3. Identify pathway to scale to more customer opportunities (related insurance outcome).

METHODOLOGY

Evaluation of available probes

Quanturi haytech temperature probes

Quanturi probes were placed in haystacks on four different farms in southern NSW along with scientific temperature sensors (Tiny Tag) for a three to four month period. The temperatures recorded by the different probes were then compared to determine if the Quanturi probes returned accurate temperature data and could be accessed via the web portal. Sixteen were used on each farm resulting in eight of the ten (Quanturi) each having two temperature sensors (Tinytag) placed 5-10cm to the left and right of the probe (Image 1). Results from the two Tinytag probes were averaged for comparison with the Quanturi probes.

Image 1: Example of layout of the two types of temperature probes at one of the sites. Quanturi probes are orange and each of the large grey loggers has four Tinytag probes attached

Incyt temperature sensors

Incyt temperature probes were placed in different locations within a large haystack for a 1–3-day period to determine if there were limitations on the ability of the sensors to communicate with the base station in large stacks.

Haystack fire

Eight large square bale of straw with temperature sensors installed were deliberately set on fire and the rate of temperature increase and differences between sensors recorded (Image 2).

Image 2: Hay stack minutes after ignition showing location of temperature probes

Fresh hay monitoring

November 2022

Four round bales of pea silage baled at ~30% moisture were unwrapped, and their temperature monitored over a four-day period (Image 3). Due to unfavourable weather conditions (hot and windy with near ripe barley crop 30m downwind) the experiment was aborted after four days with copious amounts of water applied to each bale using a firefighting unit. Temperature continued to be monitored and water was again applied the next day and then one day after this the bales were pulled apart for fire safety.

Image 3: Pea silage showing sensor installation

November - December 2022

Large square bales of oaten hay were baled at 3 moisture contents (~23%, 14%, and farmer's normal) at three different densities (farmer's normal, higher and lower). Temperature probes were placed in the bales immediately after baling for 28 days and hay samples taken at bays and 14 and 28 days after baling for moisture and nutritional analysis.

April – May 2023

Large square bales of lucerne baled at ~45% moisture for silage were obtained and their temperature monitored for 35 days. Probes were placed in the hay 3 days after baling. Hay samples were taken every seven days for moisture analysis and the first and last samples were sent for nutritional analysis.

RESULTS

Evaluation of available probes

Quanturi haytech temperature probes

The location of the base station was found to be important, one site of marginal mobile phone coverage had few readings transmitted to the web interface until the base station was relocated. The signal from the Quanturi probes to the base station was able to be transmitted a reasonable distance with one base station located over 50 metres from the probes. No experiments were undertaken to determine the maximum amount of separation that would still allow data transfer.

On most occasions all sensors (both types) within a single bale gave similar readings (Figure 1) however probes installed in round bales stored on the ground with no cover showed the placement of probes was important. Probes nearer the top of the bale had greater temperature fluctuations than those placed in the centre of the flat side.

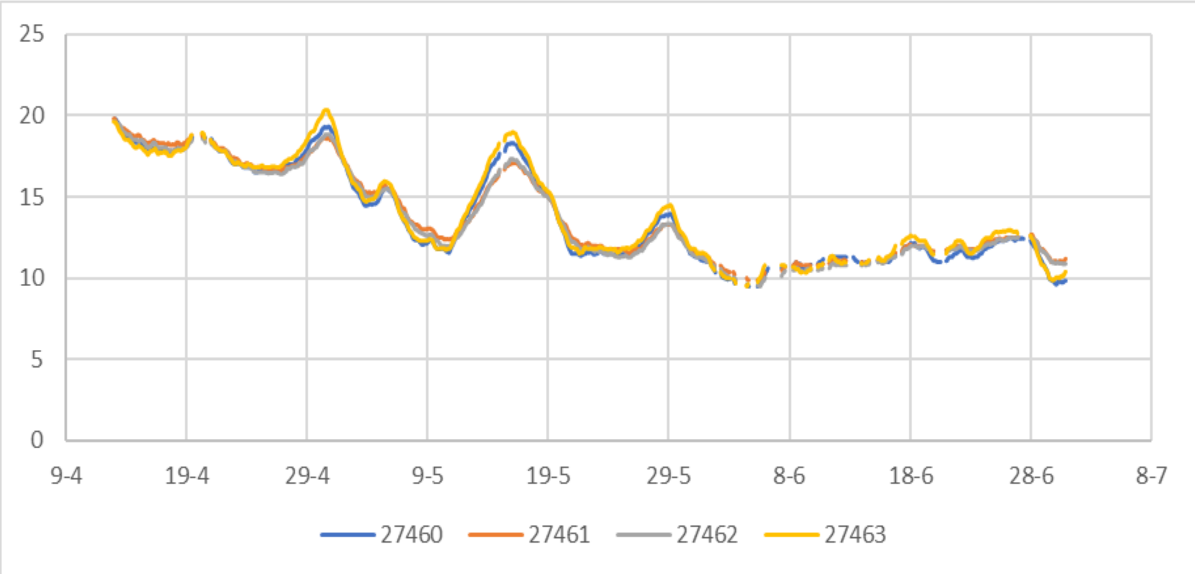


Figure 1: Comparison of four Quanturi probes in single bale

The Quanturi probes were shown to give similar results to the scientific (Tinytag) probes (Figure 2). The longer Quanturi probes (40cm long) gave more consistent temperatures through each day than the Tinytag probes (15cm long) with greater diurnal temperature fluctuations. This confirms the need to monitor the centre of bales as it shows temperature is lost from the edges of bales when ambient temperature decreases. Some Quanturi probes did give readings that differed from other probes in the same bales, but in all cases the two Tinytag probes paired with that sensor gave similar results, confirming the accuracy of the observed readings.

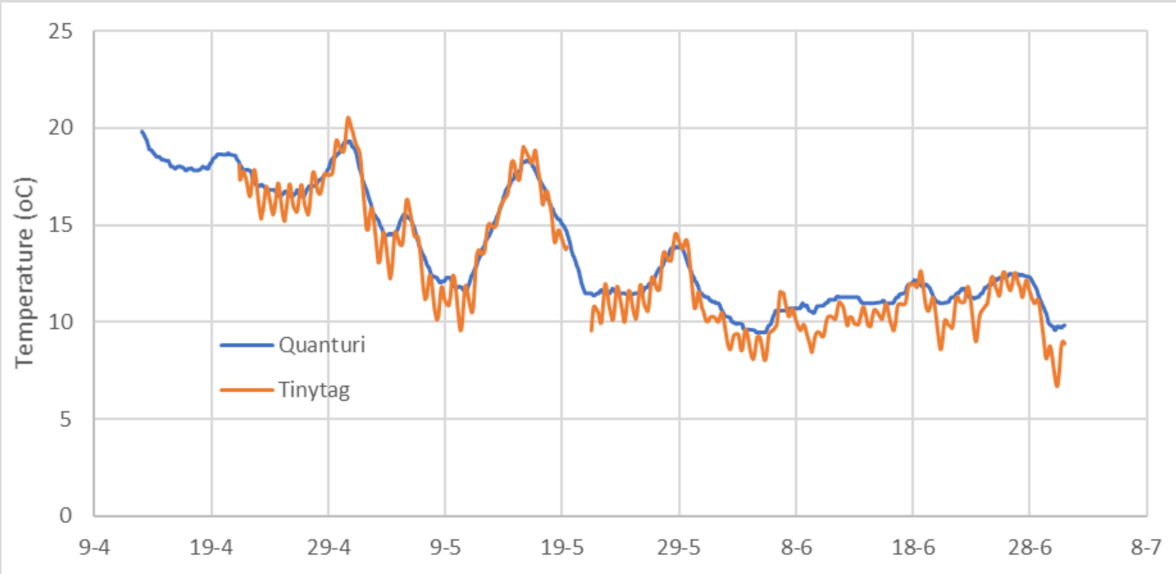


Figure 2: Comparison of Quanturi and Tinytag probes for one Quanturi probe

Incyt temperature sensors

This experiment is still ongoing but at present on all but two occasions the base station has been able to receive data from the sensors, however the sensors are now being placed at locations further from the base station. One potential limitation of these sensors is that they are puck shaped (approx. 25 mm x 25 mm x 15 mm) not a probe so they cannot measure the temperature in the centre of a bale, rather they are measuring the temperature in the centre of the stack. They also at present only transmit temperature reading every six hours compared to hourly for the Quanturi probes.

Haystack fire

The temperatures reached up to 800° C within 10 minutes of the fire being lit (Figure 3). The data obtained showed the rapid increase of temperatures early, and also the insulating effect of the hay with the sensors below the stack not showing any temperature increase until the stack was pulled apart to extinguish the fire. During the fire infra-red sensors showed that were the surface was burning it could be over 500°C but if the surface were not alight it may be only 30°C even though these areas were only 30cm apart. This reinforces the need for temperature sensors both within bales and within stacks.

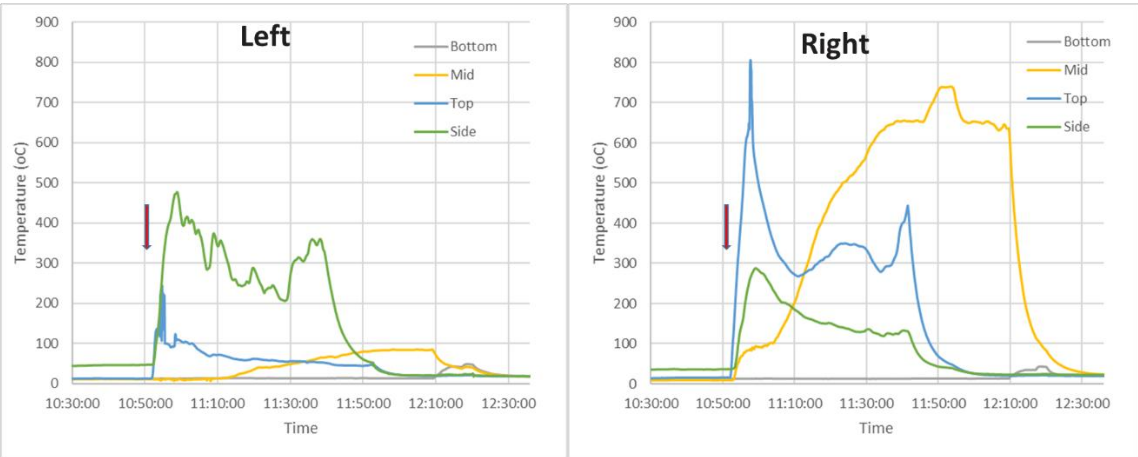


Figure 3: Temperature profile of stack after fire ignition (red arrows). Probes fell from their initial as the stack burned (Left top fell to side ~10:55, left side (and top) fell away from stack ~11:45, right top to side ~10:58, ride side (and top) fell away from stack ~11:40.

Fresh hay monitoring

November 2022

The bales rapidly increased to a temperature of 50°C at which stage they were saturated with water for safety reasons. However after this, and when water was again applied the next day, temperatures within the bale increased rapidly (Figure 4). Between 12 and 24 hours after the water was added temperature increases of up to 5°C per hour were recorded while half way between the centre and edge of the bale temperature increase averaged approximately 2.5°C per hour across the entire 24-hour period.

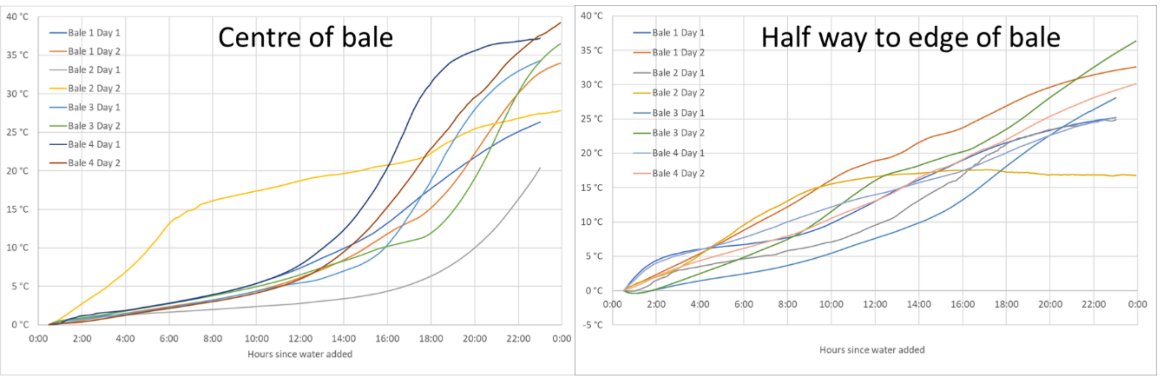


Figure 4: Increase in temperature in 24-hour period after water added to bales

November - December 2022

The hay baled at the farmer's normal moisture level (low) increased in temperature for the first 2-3 days after baling, after this period most changes in temperature reflected that of the daily maximum air temperature for the day, regardless of bale density (Figure 5).

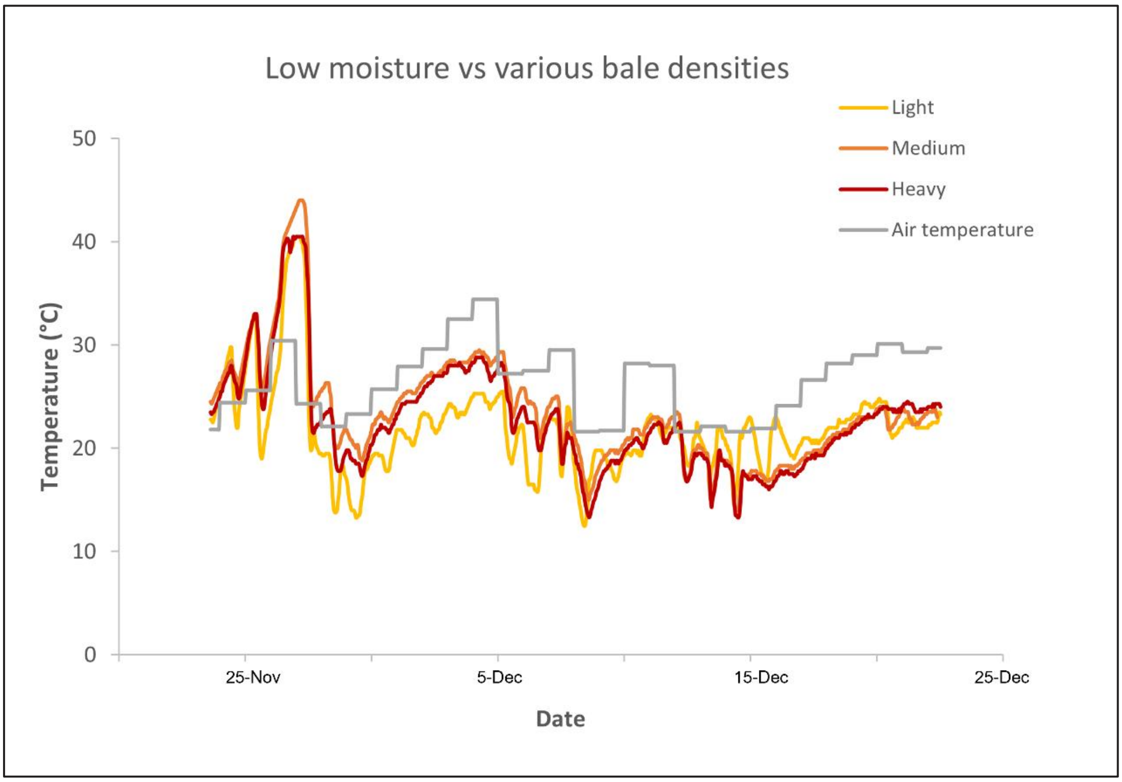


Figure 5: Temperature fluctuations in bales baled at three densities when baled at the farmer's standard moisture level

However when baled at the highest moisture content, temperatures reached a higher maximum (65°C) and bale density influenced both the increase and decrease in temperatures. The high density having the higher maximum temperature, and, after the initial temperature decline the lower density bales showing greater declines in temperature but also more rapid increases. This is possibly a result of the reduced insulation effect due to the less dense hay (Figure 6).

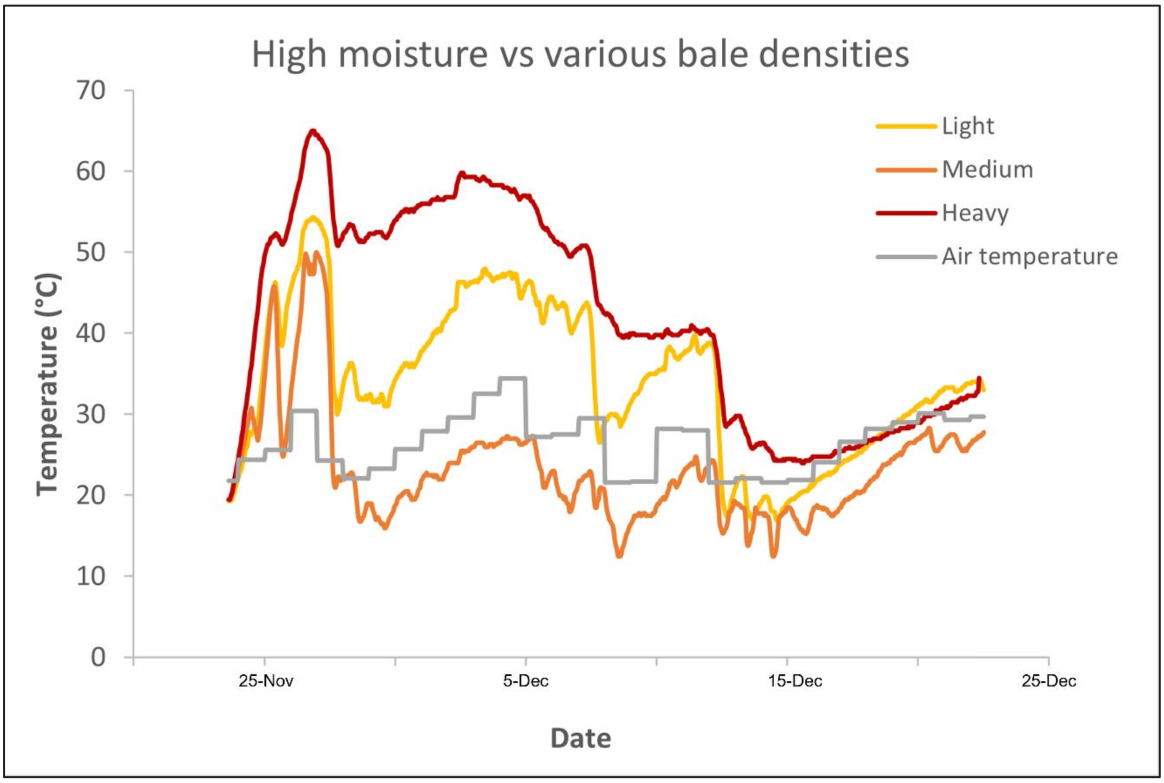


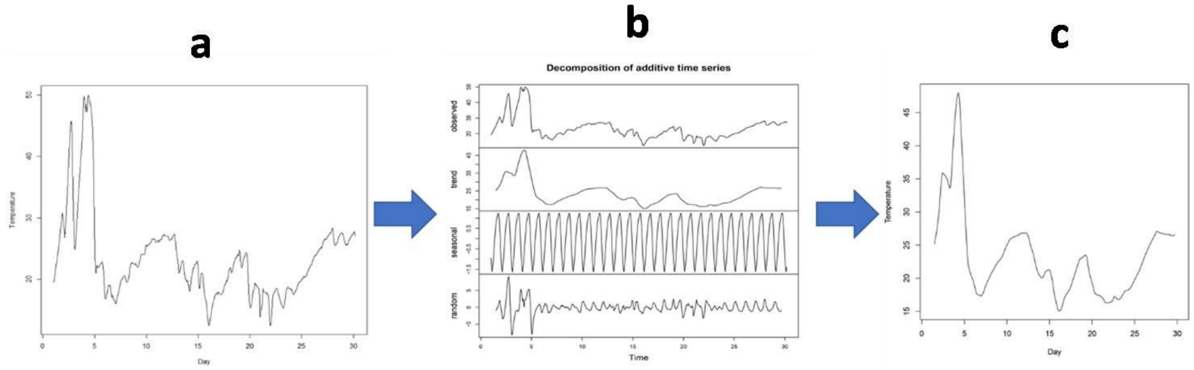
Figure 6: Temperature fluctuations in bales baled at three densities when baled at the 23% moisture level

The samples taken from the bales for nutritional analysis showed no decline in hay quality or increase in mould levels over the time of the experiment.

Time series modelling of temperature data

Modelling was undertaken to determine the actual difference in temperature after removing other factors involved (e.g. air temperature). This used the high moisture medium density bales from Figure 6 showing the underlying influence of the microbial and chemical reactions in the bale (Figure 7).

Internal bale temperatures recorded from hay bales over time can possibly be used to create time series modelling to better understand the trend of temperature rise during storage.
It is evident from the time series that there seems to be seasonal variation in the temperature data (Figure 7a); as there is a peak after certain period followed by sharp decrease. Again, it seems that the random fluctuations also seem to be roughly constant in size over time and do not depend on the level of the time series. Thus, this time series can probably be described by decomposing the time series.



1. Actual temperature series after plotting recorded temperature data

2. Generating various components of the time series data (i.e. trend component, seasonal component and irregular/random component)

3. Subtracting seasonal component/variation from timeseries data to get the actual trend

Figure 7: Time series modelling for high moisture, medium density bales showing the components of temperature change during storage

Decomposing a time series means separating it into its constituent components, which are usually a trend component and an irregular component, and if it is a seasonal time series, a seasonal component (Figure 7b). As we have a seasonal time series that can be described using an additive model, the next step is to seasonally adjust the time series by subtracting the estimated seasonal component from the original time series to get the actual trend (Figure 7c).

The initial spike in internal bale temperature immediately after baling is due to the respiratory activities by plant cell and microorganisms followed by subsequent heating cycles representing activity of various groups of microorganisms at different stages during storage.

April – May 2023

The initial rapid increases due to microbial activity was not recorded, as the temperature sensors were not placed in the bales for several days after baling. However, increases in temperature after the dip that was observed between 40 and 50°C (Figure 5 and 6) was recorded as this dip can be seen early in Figure 8.

Temperatures increased for the next four days and then stabilised, with some fluctuations after about 14 days (Figure 8). These fluctuations represent heat loss from the bales surface and subsequent heat exchange within the bale, but the insulating properties of hay are shown in that these fluctuations are not as large as that of the ambient air temperature (Figure 9).

While the results of the nutritional testing have not been received, personal observations expect that there will be a marked increase in mould present in the final samples when compared with the initial samples.

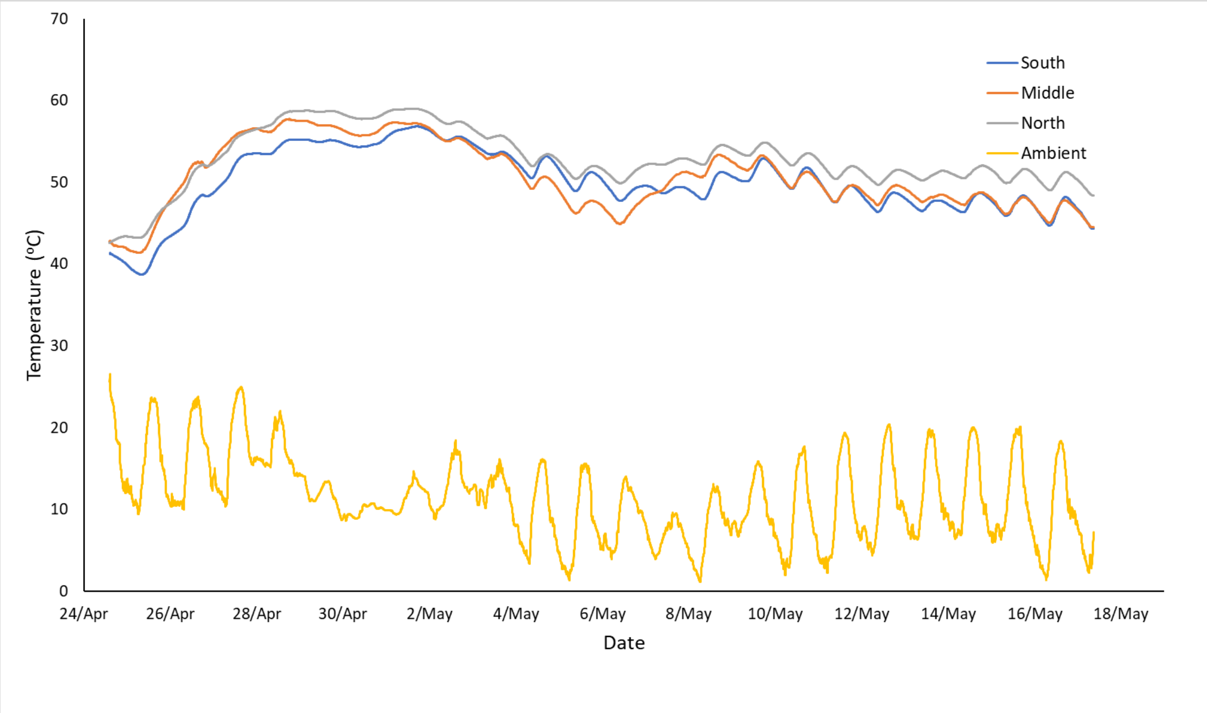


Figure 8: Temperature for three bales baled at 45% moisture and the ambient air temperature

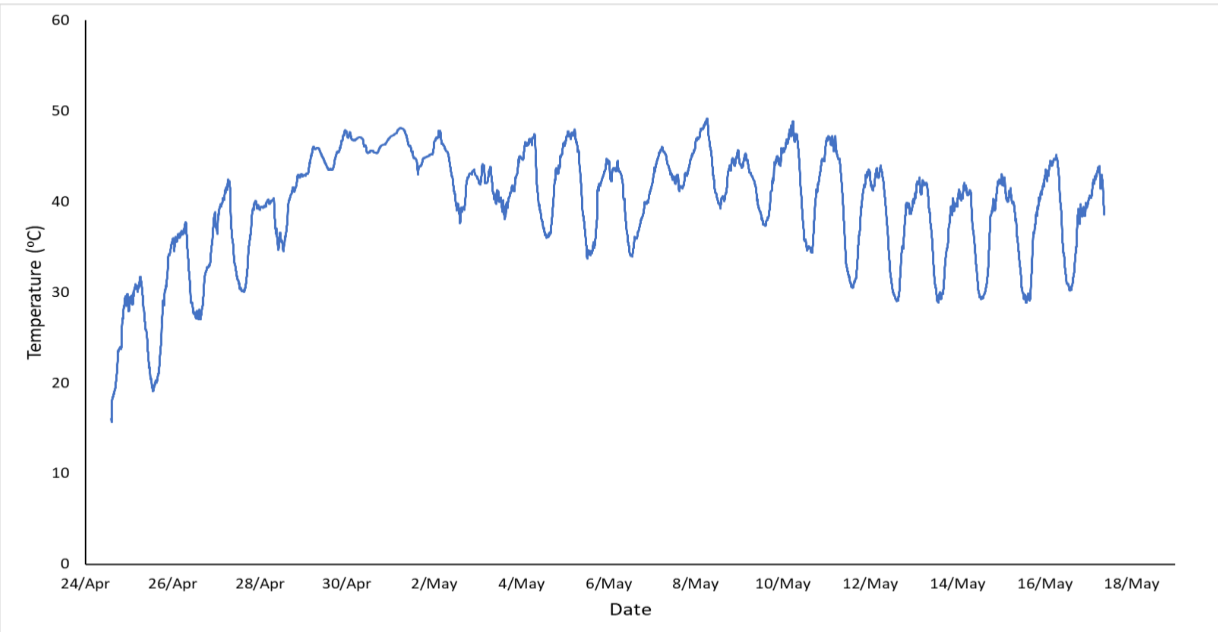


Figure 9: Mean difference in temperature between the bales and the ambient air temperature

CONCLUSIONS AND RECOMMENDATIONS

From initial investigations it appears that the Quanturi probes are a suitable method of measuring temperature in haystacks. The reason for any probes recording temperatures different from other probes in the same bale has been either explained or confirmed after comparison with the Tinytag sensors or by their location in the bale.

The length of the probes (40cm) results in the temperature sensor being buffered from outside fluctuations in temperature, therefore providing a more accurate reading of the actual internal temperature at the location where the combustion process is most likely to be initiated. This means that the probes need to be located such that the tip is not pushed towards the edge of a bale but centrally located.

It appears that 50-60^{o}C is a critical value for initial temperature alerts as we have observed hay cooling down from this temperature but with differing impacts on quality. There are some caveats with this finding; these bales were not in large haystacks, but either individual bales or single rows stacked two high, so heat loss would be greater than in a stack, and secondly, ambient temperature and humidity may play a part in both the heating and cooling of hay but also in the impacts high moisture and temperature may have on hay quality.

NEXT STEPS

Whilst the project alongside Food Agility can be deemed a success, and the project parties of Myriota, CSU & IAG all worked well together, the consensus is that we're only just scratching the surface.

In terms of next steps:

1) IAG to finalise some internal business case model to determine what the scaling of this solution would look like, and the financial implications attached to this.
2) Importantly, research still needs to be conducted with regards to what the critical (red) temperature is within the RAG status.

PROJECT TEAM

- **IAG**: Nicholas Carabine, Scott Gunther, Rebecca Schot-Guppy, Shen Lu & Mackenna Powell (WFI)
- **Myriota**: Paul Sheridan, Steve Winnall & Scott Cramer
- **CSU**: Dr John Broster, Imtiaz Chowdhury & Joe Moore

Haystack Monitoring

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30 May 2023
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